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***TM 9–8000**
TO 36A–1–76

TECHNICAL MANUAL No. 9–8000
TECHNICAL ORDER No. 36A–1–76

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
WASHINGTON 25, D. C., *27 January 1956*

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PART ONE

INTRODUCTION

CHAPTER 1

GENERAL

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1. Purpose

This manual is published to disseminate basic descriptive information in the field, and in service and troop schools, to teach what the automotive vehicle is and how it works. It also contains information which makes the publication a convenient reference manual.

2. Scope

a. Subject Matter and Presentation. This text explains the automotive vehicle in general. The explanations avoid reference to any specific vehicle or unit wherever possible. Since existing publications cover operation and maintenance of vehicles, these subjects have been omitted. The flow of power is traced from its development in the engine to its final outlet at the wheels, the units being discussed in the order in which they contribute to the power flow. For this reason, the ignition system is treated separately from the rest of the electrical system. Diesel and gasoline engines, except for their fuel systems, are explained together, as are radial and in-line engines. After the flow of power is traced to the wheels, those chassis components, sometimes referred to as running gear (i. e., steering system, brakes, wheels and trucks, and frames) are explained; then hulls and bodies; and finally such miscellaneous items as special equipment and trailers. Those features of motorcycles and scooters that differ from other conventional automotive vehicles are also explained.

b. Emphasis. Wheeled vehicles have been emphasized for two reasons: first, tracklaying vehicles, in the main, employ special adaptation with the same fundamental principles of wheeled vehicles; second, instruction will be facilitated by the reference to wheeled vehicles because most parts are more accessible and more easily seen than on tracklaying vehicles. Again to aid instruction, the military vehicle has been correlated with commercial vehicles that may be familiar to the student.

3. Characteristics of Military Vehicles

a. Terminology. For a better understanding of the general sections that follow, and other references, the following terms are defined. Terms pertaining to the mechanics of the automotive vehicle are defined in the appropriate portion of the text. Refer to the index to locate these definitions and explanations.

(1) *All-wheel drive.* A drive in which all wheels receive power for propelling the vehicles.

(2) *Angle of approach.* The angle of the maximum grade that a vehicle can approach on the horizontal and start to climb with no part, except tires or tracks, coming into contact with the grade.

(3) *Angle of departure.* The angle of the maximum grade from which a vehicle can depart on the horizontal without any part, except tires or tracks coming in contact with the grade.

(4) *Armor.* Armor is any type of enclosing structure used for the protection of military vehicles from gun fire.

(5) *Convertible.* A vehicle designed to be operated either as a track vehicle or as a wheeled vehicle.

(6) *Cross country.* Away from surface and improved roads. Over virgin terrain, sand, rocks, hills, through water and/or swampland. (See also fordability in (10) below.)

(7) *Cruising range.* The total mileage a vehicle can operate on the contents of its fuel tanks.

(8) *Drawbar pull.* The pull exerted at the pintle.

(9) *Flotation.* The amount of load carried by each square inch of projected contact area of the vehicle's tires or tracks. At zero penetration, the flotation unit pressure for a wheeled vehicle is the same as the air pressure in the tires.

(10) *Fordability.* Expressed in inches of water that a vehicle can go through under its own power.

(11) *Grade ability.* The maximum grade that a fully loaded and equipped vehicle can climb at constant speed on a smooth concrete course when operating a specified gear range.

(12) *Ground clearance.* The distance between level ground and the lowest point on the undercarriage of the vehicle.

(13) *Military characteristics.* The basic service requirements of a vehicle.

(14) *Payload.* The weight of cargo or passengers including crew which may be safely imposed on vehicle.

(15) *Passenger capacity.* The number of passengers, including operating personnel, that a vehicle is designed to carry.

(16) *Stowage.* Equipment stowed within the vehicle.

(17) *Tractive factor.* The thrust or force of the tire against the ground per pound of vehicle weight that is available at the tire surface for moving the vehicle.

(18) *Turning radius.* The radius of the arc described by the center of the track made by the outside front wheel of a vehicle when making its shortest complete turn.

(19) *Vehicle gross weight.* Weight of vehicle fully equipped and serviced for operation, including crew, plus maximum allowable payload of cargo and passengers.

(20) *Net weight.* The weight of fully equipped vehicle in operating condition with fuel, lubricants, and water, but without crew or payload unless otherwise specified.

b. Transport Vehicles. Military transport vehicles are divided into two general categories: administrative and tactical. Administrative vehicles are commercial vehicles having the minima of modifications to adapt them to military service; in some instances, no modification whatsoever is made. Administrative vehicles are primarily used at posts, camps, and stations, and to fulfill requirements for vehicles that operate chiefly on prepared roads. Tactical vehicles are primarily used as TOE equipment of tactical organizations and, in most instances, are specially built to army specifications. Tactical vehicles pose many special features which are not ordinarily required in commercial vehicles, including (1) through (22) below.

(1) All-wheel drive for maximum mobility.

(2) Combat tires to eliminate tire punctures and resultant breakdown during operations.

(3) Sturdy radiator and headlamp guards as protection from branches and brush in blackout operations in the field.

(4) Sturdy front and rear bumpers as protection against collision during blackout convoys (training and actual combat operations) and as an aid in assisting mired vehicles.

(5) Towing hooks and pintles for towing nonpowered vehicles and for use with vehicles being towed.

(6) Front axle declutching unit for relieving tires and driving mechanism while operating on surfaced roads.

(7) Maximum angles of approach and departure to facilitate vehicle operation over uneven and rough virgin terrain.

(8) Deep fordability to enable vehicles to cross streams under their own power.

(9) Equal performance ability of all types and sizes of vehicles in order to realize maximum movements of convoys in a prescribed time period.

(10) Maximum ground clearance consistent with road stability to permit operation over virgin terrain and through marsh and mud.

(11) Clearance between the engine oil pan and the front propeller shaft sufficient to prevent contact under all conditions of operation.

(12) Flexible type of unit-assembling mounting, particularly engine transmission and transfer case. Preferred type for power train unit is 3-point suspension with circular trunnion as one support.

(13) Sloping engine hoods for close clear

vision of roads and combat light during blackout driving either singly or in convoy.

(14) Combat lights, front and rear, for blackout driving.

(15) Scavenging oil circulating pump connected to the front and rear of the oil pan to return oil to the main oil pump where it can be circulated by the oil pump during steep slope operation.

(16) Auxiliary fuel filters to eliminate water and sediment from fuel before it reaches the fuel pump. Accumulation of dirt and moisture is increased in military service because of the absence of protection from the elements during field fueling operations.

(17) Radio frequency interference suppression to eliminate interference with military radio communication and informing enemy listening posts of vehicular movements.

(18) Crankcase ventilation to reduce corrosion of reciprocating parts and maintain stable lubrication by removing fuel light ends and moisture of condensation from the crankcase.

(19) Arcticizing equipment to provide easy starting of engines in subzero temperatures by use of heaters and insulating covers on batteries and to engine compartment.

(20) Desertizing equipment, which consists of large-section, low inflation tires; auxiliary radiator tank to store main radiator overflow; pressure-type radiator cap to prevent coolant loss by evaporation and overflow loss when traveling down steep grades; fuel tank filler pressure caps to assist flow of fuel under vapor lock tendencies.

(21) Wheels, demountable at the hub to permit quick changes without disturbing the wheel bearings and, in addition, to enable front wheels to be assembled in duals when required.

(22) Full-floating type axles to insure against loss of wheels in the event of broken axle shafts.

c. *Combat Vehicles.*

(1) So far as automotive design principles are concerned, combat vehicles are, in all respects, subject to the same limitations as those of a more conventional type. In addition, designs must be such as to permit successful operation, with one or more of the following features present:

(*a*) Power plant and power train fully inclosed by armor.

(*b*) Engine located at front or rear of vehicle.

(*c*) Mobility in temperatures from −65° to 125° F.

(*d*) Operation in mud and under extreme dusty conditions.

(2) Tanks and armored cars are usually built on a hull fabricated of armor plate. Scout cars are usually of conventional basic design with armored bodies.

(3) Performance will generally include:

(*a*) Sixty percent grade ability.

(*b*) Maximum drawbar pull at least 80 percent of gross weight.

(*c*) High gear drawbar pull at least 8 percent of gross weight.

(*d*) Average speed 3 mph or less.

(4) In addition to satisfying the military need for which the combat vehicle may have been designed, crew comfort and safety must be provided by:

(*a*) Adequate ventilation.

(*b*) Padding of interior surfaces.

(*c*) Careful attention to seating.

(*d*) Adequate design of drivers' turret and escape hatches and locks for same.

(*e*) A fire extinguisher installation adequate as to coverage and controls.

(*f*) Avoidance of overly restricted interior dimensions.

4. History of Military Vehicles

In 1912, four commercial trucks were purchased by the U. S. Army for experimental purposes. Thus, motor vehicles were introduced as a means of transporting military personnel, supplies, and equipment. By 1916, when the Punitive Expedition was sent against the Mexican bandits, interest had been stimulated to the point that a fleet of trucks, absolutely unstandardized and of many different makes, was assembled at the Mexican Border and used in the campaign. It was discovered then that commercial transportation did not meet military requirements on operations over rough terrain and in the vital requirements of maintenance and repair. This discovery prompted the initiation of standardized designs of operating equipment and various modifications to meet military requirements. As a result, the thousands of vehicles used in World War I were to a great extent standardized, and possessed a moderate degree of interchangeability. The slow, strangulating trench warfare of that war caused the development of an automotive vehicle used solely for combat purposes. As such, the tank was introduced by the British in France in 1916; subsequent American tanks were for the most part copies of British models. In the period between the two World Wars, American design and experimentation were carried on to develop a fleet of military wheeled vehicles that were entirely standardized and that had a high degree of interchangeability. Under the program, industry began to produce vehicles with both front and rear wheel drives. This was a feature that was required of a military vehicle for successful operation over any terrain but found only in special commercial equipment. After German tanks and combat vehicles proved so tragically successful against the Polish, French, and British armies in 1939 and 1940, American tank development was necessarily accelerated. In the race to develop superior combat vehicles, the United States equaled and in some instances surpassed the Axis powers; in the race of production, the United States was eminently successful and was able to send overwhelming quantities of automotive material against the enemy to help bring about their defeat.

CHAPTER 2

ORGANIZATION OF THE MANUAL

5. Major Components

Many different ways are used to group vehicle units and assemblies. The method employed in this text has been chosen because it more readily lends itself to a logical and simplified development of the material to be presented. In this grouping are five major components:

a. Power Plant. The power plant consists of the engine (diesel or gasoline), and attached fuel, ignition, cooling, and lubricating systems.

b. Power Transmission System. The power transmission system includes all mechanisms by which power is transmitted from the engine to the wheels. These mechanisms are the clutch, transmission, transfer assembly, propeller shafts, universal joints, final drive assembly, differential, and drive axles.

c. Electrical System. The electrical system includes electrical attachments other than those in the ignition system, such as the battery and the generating, starting, and lighting systems.

d. Chassis. The units in the chassis are the frames, brakes, wheels, tires, tracks, suspension system, and steering system.

e. Body. The body is the cargo or personnel-carrying portion of the vehicle, and includes hulls and bodies.

6. Classification of Vehicles

a. General. The term *vehicle*, as used in the Army, includes all wheeled, tracklaying, combined wheeled and tracklaying equipment, and chassis powered by a self-contained power unit; trailers and semitrailers towed by vehicles; and bicycles.

b. Classification of Vehicles According to AR 700–105.

(1) *General-purpose vehicles.* General-purpose vehicles are motor vehicles designed to be used interchangeably for movement of personnel, supplies, ammunition, or equipment, or for towing artillery carriages, trailers, or semitrailers, and used without modification to body or chassis to satisfy general automotive-transport needs. The 2½-ton 6 x 6 cargo truck is a general-purpose vehicle, for it is used as a general-transport vehicle and has a standard, unmodified chassis.

(2) *Special-equipment vehicles.* Special-equipment vehicles are motor vehicles, the chassis of which are, except for minor alterations, identical with those used in general-purpose vehicles, but which have a special body or special equipment mounted thereon. The ordnance shop truck (ordnance maintenance truck, 2½-ton 6 x 6) is in this class because a special body to house the shop has been mounted on the chassis of a general-purpose vehicle 2½-ton, 6 x 6.

(3) *Special-purpose vehicles.* Special-purpose vehicles are motor vehicles designed and intended for a specialized requirement for which no general-purpose vehicle chassis can be adapted. This category includes items that are specified from time to time by the technical services. All tractors, regardless of size or intended purpose, will be classified as special-purpose vehicles. They are separate and distinct from combat vehicles.

(4) *Combat vehicles.* Combat vehicles are special-purpose vehicles, with or without armor and/or armament, which are designed for specific fighting functions. Limited armor protection and/or armament mounted or installed on general-purpose, special-equipment, or on special-purpose vehicles of otherwise noncombat type, will not operate to change the classification of such vehicles to combat vehicles.

(5) *Trailers.* Trailers are vehicles designed to be towed and are provided with a

drawbar or tongue for attachment to a coupling mounted on the towing vehicle.

(6) *Semitrailers.* Semitrailers are vehicles designed to be towed and are supported in part by a prime mover through a fifth wheel or similar coupling.

c. Classification by Ground Contact. Under these general classifications, vehicles may be further subclassified into wheeled, tracklaying, and half-track vehicles. Wheeled vehicles may be classified by the number of wheels and the number of driving wheels. Where such data as 4x4, 6x4, 6x6 and etc., appear in vehicular nomenclature, the first figure indicates total number of wheels and the second figure indicates number of driving wheels. It should be noted that all 6-wheel vehicles have three axles, that is, wheels are considered a unit whether they are single (one tire) or dual (two tires). Tracklaying vehicles are so called because the tracks serve the purpose of providing a supporting platform of relatively large area under the road or suspension wheels of the vehicles, with rails or other guiding elements on the upper side. Half-track vehicles include all vehicles in which a portion of the weight is carried on wheels at the front, capable of being steered and the remainder of the weight carried on tracks located at the rear.

PART TWO

ENGINES

CHAPTER 3

CHARACTERISTICS OF ENGINES

7. Engine Construction

The first step in understanding automotive engine construction and operation is to understand what goes on inside the engine. No matter how many cylinders an engine has, whether 1, 2, 6 or 12, the same actions take place in each cylinder. Since the diesel engine is mechanically similar to the gasoline engine we can learn about engine construction and operation by studying a single-cylinder engine (fig. 1). This engine is a 4-stroke-cycle (fig. 4), internal combustion, gasoline engine; these terms are explained in subsequent paragraphs.

a. Cylinder and Piston. A cutaway of a single cylinder gasoline engine is shown in figure 1. The upper, or head end is closed by a cylinder head, but the lower end is open. The piston is a hollow metal tube with the top end closed. It is a close-sliding fit in the cylinder, which means it can move up and down in the cylinder. This up-and-down movement, produced by the burning of fuel in the cylinder, results in the production of power from the engine.

b. Connecting Rod and Crank. The up-and-down movement of the piston is called *reciprocating motion.* This reciprocating motion must be changed to rotary motion so the wheels of the vehicle can be made to rotate. The change is accomplished by a crank on the crankshaft and a connecting rod which connects between the piston (fig. 2) and the crank. The connecting rod is connected to the piston by a piston pin. The pin passes through bearing surfaces in the piston and the connecting rod. The lower end of the connecting rod is attached to the crankpin on the crankshaft. As the piston moves up and down in the cylinder, the upper end of the connecting rod moves up and down with it. The lower end of the connecting rod also moves up and down but, because it is attached to the crankpin on the crankshaft (fig. 3), it must also move in a circle with the crankpin. Each movement of the piston from top to bottom or from bottom to top is called a *stroke.* The piston takes two strokes as the crankshaft makes one complete revolution, an upstroke and a downstroke. When the pis-

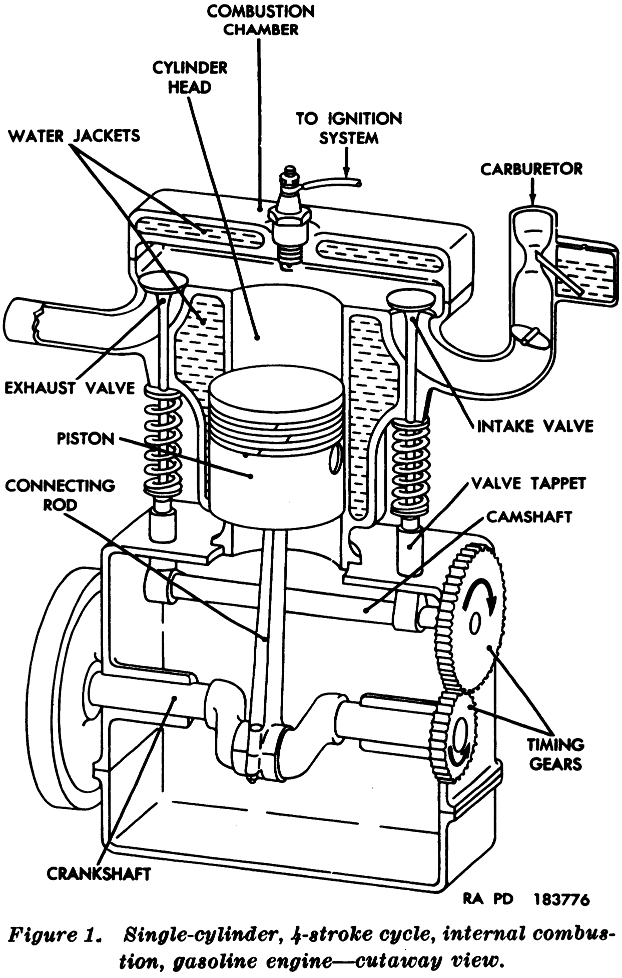

Figure 1. Single-cylinder, 4-stroke cycle, internal combustion, gasoline engine—cutaway view.

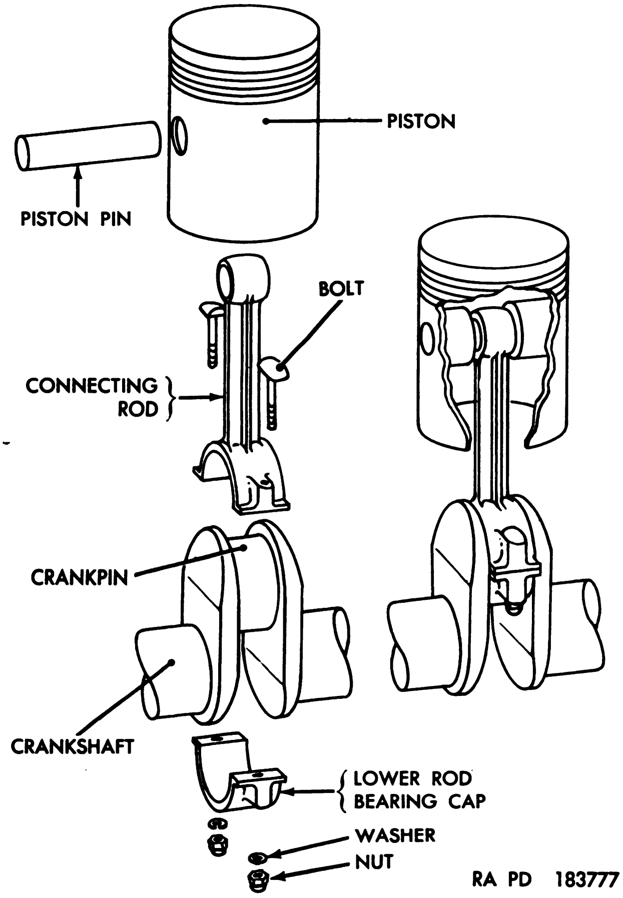

Figure 2. Piston, connecting rod, and piston pin.

ton is at the top of a stroke, it is said to be at top dead center (TDC). When the piston is at the bottom of a stroke, it is said to be at bottom dead center (BDC). These positions are called rock position (par. 11*c*).

c. Valves. There are two valves (fig. 1) at the top of the cylinder. A valve is an accurately machined plug that fits into a machined opening at the top of the cylinder. When the valve is resting in this opening, it is said to be *seated.* When a valve is so positioned, it is *closed* and the opening is sealed off. When the valve is pushed off its seat, it is *opened.* The two valves in the cylinder are closed part of the time and opened part of the time. The valve mechanism that causes the valves to open and close is discussed in paragraph 8*e*. One of the valves, called the *intake valve*, opens to admit a mixture of fuel and air into the cylinder. The other valve, called the *exhaust valve*, opens to allow the escape of burned gases after the fuel-and-air mixture has burned.

8. Engine Operation

a. Intake Stroke. The actions that take place within the engine cylinder may be divided into four basic parts, which are called *strokes.* The first stroke in the sequence is called the *intake* stroke (fig. 4). During this stroke, the piston is moving downward and the intake valve is open. This downward movement of the piston produces a partial void, or vacuum, in the cylinder, and air rushes into the cylinder past the opened instake valve. This is somewhat the same effect as when drinking through a straw. A partial vacuum is produced in the mouth and the liquid moves up through the straw to fill the vacuum (fig. 5). In the engine, the inrushing air passes through the carburetor (ch 5) before it enters the cylinder. The carburetor charges the air with gasoline vapor to produce a combustible mixture.

b. Compression Stroke. When the piston reaches bottom dead center at the end of the intake stroke and is therefore at the bottom of the cylinder, the intake valve closes. This seals the upper end of the cylinder. As the crankshaft continues to rotate, it pushes up, through the connecting rod, on the piston. The piston is therefore pushed upward and compresses the combustible mixture in the cylinder; this is called the *compression* stroke. The mixture is compressed to about a sixth or a seventh of its original volume. This is the same as taking a gallon of air and compressing it until a little more than a pint of air is left. Compressing the mixture in this way makes it still more combustible; the energy in the fuel is concentrated into a smaller space.

c. Power Stroke. As the piston reaches top dead center at the end of the compression stroke and therefore has moved to the top of the cylinder, the compressed fuel-air mixture is ignited. This ignition is produced by the ignition system. The ignition system causes an electric spark to occur suddenly in the cylinder. The spark sets fire to the fuel-air mixture. The mixture burns so rapidly that it might be said to explode. The pressure in the cylinder goes up to as much as 400 psi. This means that the force pushing on the end of a 3-inch piston would be more than 2,500 pounds. This force, or thrust, pushes the piston down. The thrust is carried through the connecting rod to the crankpin on the crankshaft. The crankshaft is given a powerful twist. This is called the *power* stroke. This turning effort, rapidly repeated in the engine and carried through gears and shafts,

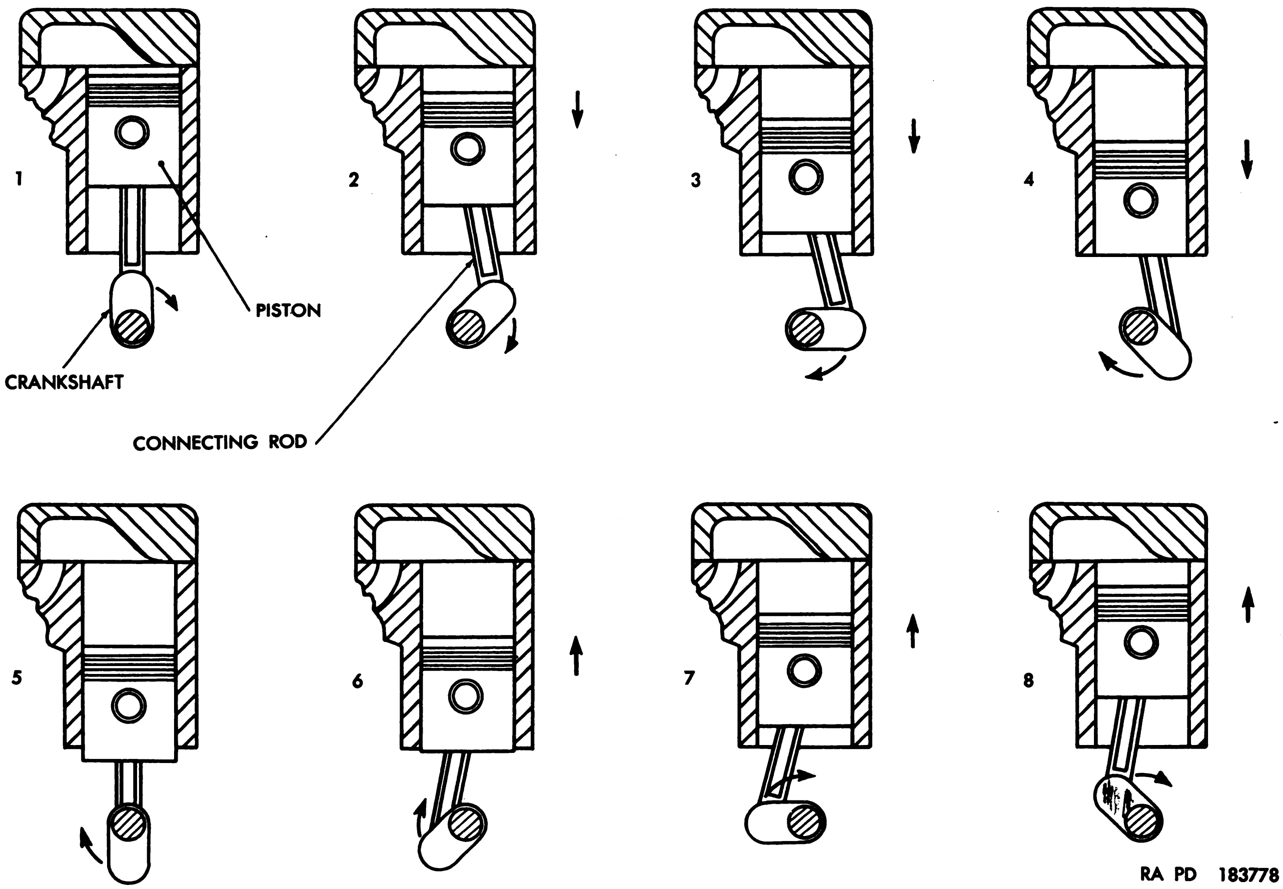

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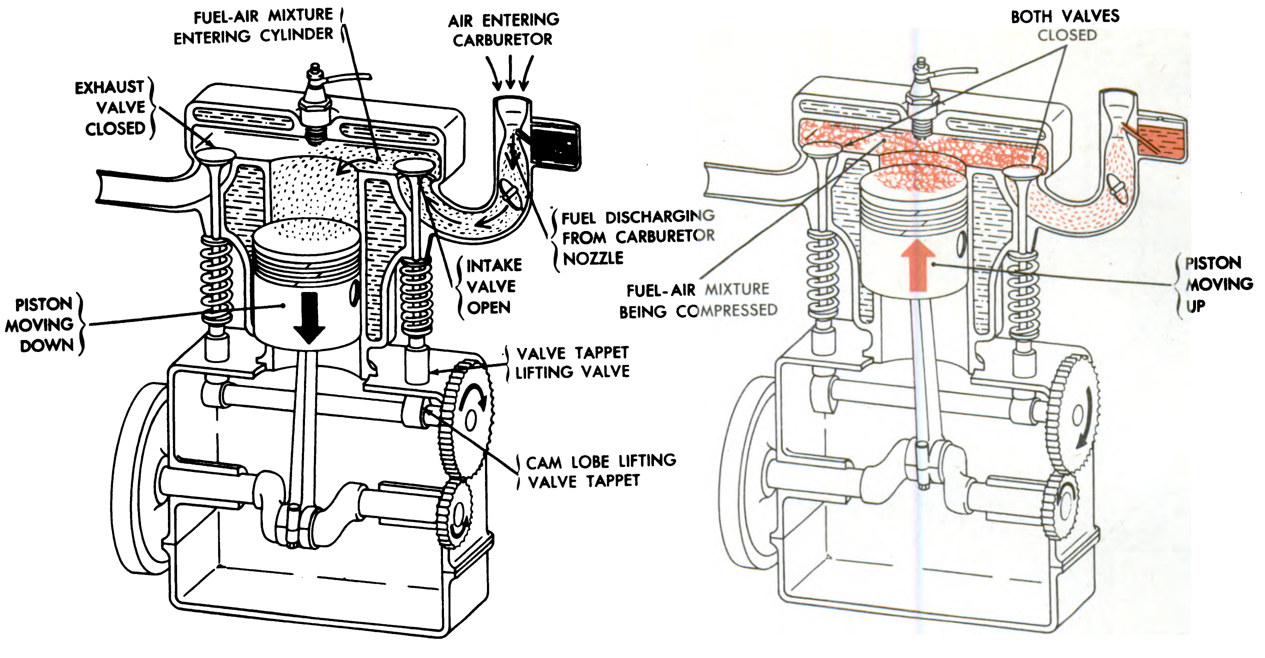
Figure 3. Relationship of piston, connecting rod, and crank on crankshaft as crankshaft turns one revolution.

will turn the wheels of a vehicle and cause it to move along the highway.

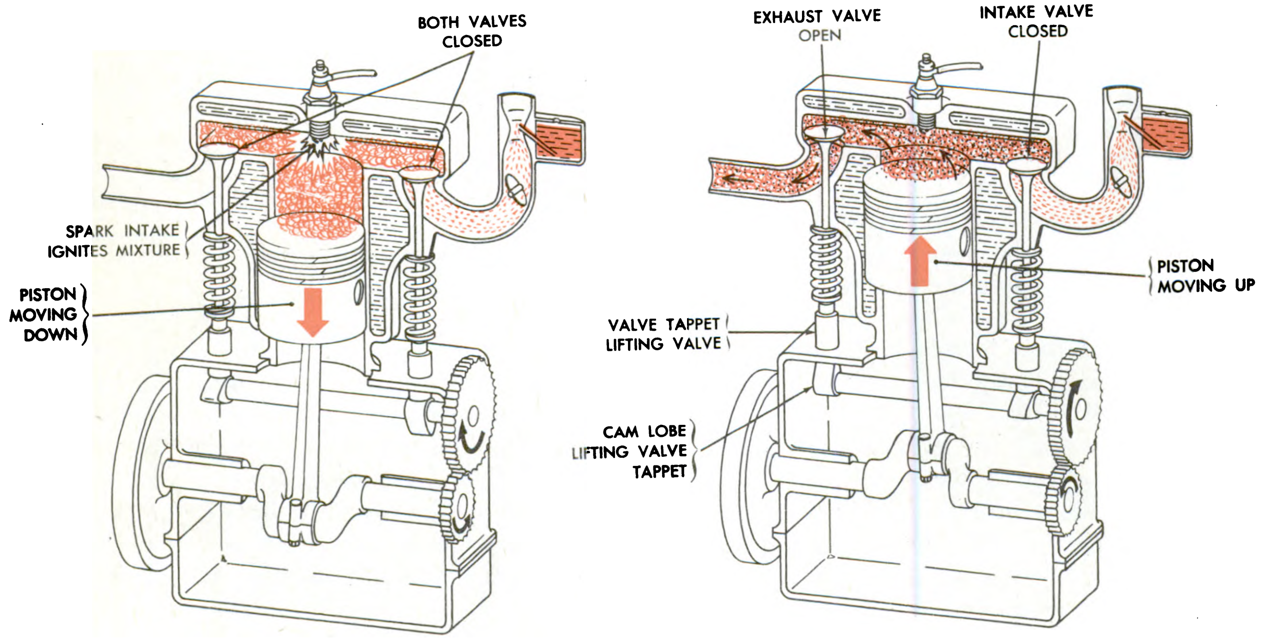
d. Exhaust Stroke. After the fuel-air mixture has burned, it must be cleared from the cylinder. This is done by opening the exhaust valve just as the power stroke is finished and the piston starts back up on the *exhaust* stroke. The piston forces the burned gases out of the cylinder past the opened exhaust valve. The four strokes (intake, compression, power, and exhaust) are continuously repeated as the engine runs.

e. Valve Mechanism Action. There are various ways of causing the intake and exhaust valves to open and close. One method is shown in figure 1. Here, a gear on the crankshaft is meshed with a second gear on another shaft. When the crankshaft turns, the other shaft must also turn. This second shaft is called the *camshaft* because it has a number of *cams on it.* These cams are simply raised sections, or collars, with high spots on them. When the camshaft rotates, the high spots (called *lobes*) move around and push away anything they are in contact with. Riding on each cam is a cylindrical valve tappet. As the lobe moves up under the valve tappet, the valve tappet is raised. This upward movement causes the valve above it to be raised also. Thus, the valve is raised up off its seat in the cylinder so that the valve opens. When the lobe on the cam moves on around out of the way, the pressure of the spring under the valve forces the valve to move down and reseat. At the same time, the valve tappet is also forced downward so that it remains in contact with the cam. The gear on the camshaft is twice as large (has twice the number of teeth) as the gear on the crankshaft. This means that the camshaft will revolve half as fast as the crankshaft. In other words, the crankshaft must turn twice for the camshaft to turn once. Thus, the valves are opened only once every two crankshaft revolutions. This is the way it should be, since there is only one intake stroke (intake valve open) and only one exhaust stroke (exhaust valve open) every two crankshaft revolutions.


FUEL-AIR MIXTURE ENTERING CYLINDER
AIR ENTERING CARBURETOR
EXHAUST VALVE CLOSED
FUEL DISCHARGING FROM CARBURETOR NOZZLE
INTAKE VALVE OPEN
PISTON MOVING DOWN
VALVE TAPPET LIFTING VALVE
CAM LOBE LIFTING VALVE TAPPET
BOTH VALVES CLOSED
PISTON MOVING UP
FUEL-AIR MIXTURE BEING COMPRESSED

INTAKE

COMPRESSION


BOTH VALVES CLOSED
SPARK INTAKE IGNITES MIXTURE
PISTON MOVING DOWN
EXHAUST VALVE OPEN
INTAKE VALVE CLOSED
PISTON MOVING UP
VALVE TAPPET LIFTING VALVE
CAM LOBE LIFTING VALVE TAPPET

POWER

EXHAUST

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Figure 4. The four strokes in the 4-stroke cycle, gasoline engine.

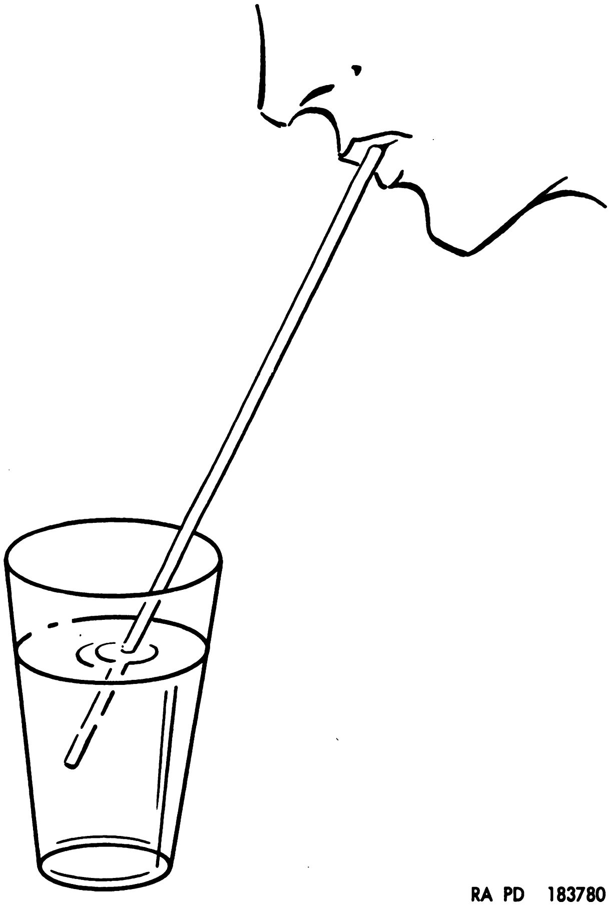
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Figure 5. Partial vacuum produced by suction.

f. Engine Accessory Systems. We have mentioned the carburetor which supplies vaporized fuel to the air passing into the engine cylinder on the intake stroke (*a* above). The carburetor is a unit in the fuel system. Another accessory system is the ignition system which ignites the compressed fuel-air mixture in the cylinder at the end of the compression stroke. A third accessory system is the lubrication system; this supplies lubricating oil to the various moving parts in the engine. The oil lubricates all parts, such as the piston, bearings, crankpin, and valve stems, that rotate or slide in or on other parts. This oil permits the parts to move easily so that little power is lost and wear of parts is kept to a minimum. A fourth system is the cooling system. In the simple engine shown in figure 1, water is used as the cooling medium. Water circulates in jackets around the cylinder and in the cylinder head. This water removes part of the heat produced by the combustion of the fuel-air mixture. This action prevents the engine from overheating and thereby being damaged. All these accessory systems are described in detail in following chapters.

9. Comparison of Engine Types

a. Internal and External Combustion Engines. In the internal combustion engine, the combustion of the fuel takes place inside the engine cylinder. This is in contrast to external combustion engines, such as steam engines, where the combustion takes place outside of the engine. Figure 6 shows in simplified form an internal and an external combustion engine. The external combustion engine requires a boiler in which a fuel is burned. This combustion causes water to boil to produce steam. The steam passes into the engine cylinder under pressure and forces the piston to move downward. With the internal combustion engine, the combustion taking place inside the cylinder is directly responsible for forcing the piston to move downward. In both types of engine, valving is arranged to permit the piston to move back upward as the spent steam (external combustion engine) or burned gas (internal combustion engine) is exhausted.

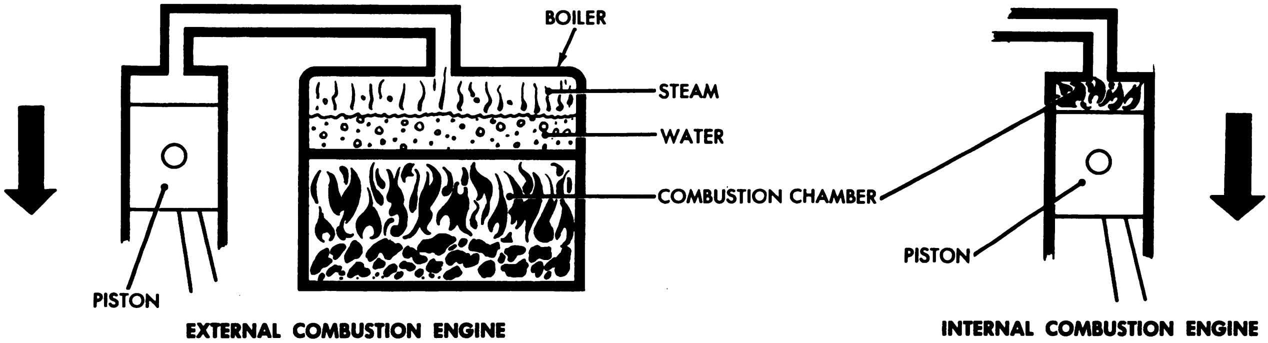

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Figure 6. Comparison of internal and external combustion engines.

b. Four-Stroke-Cycle and Two-Stroke-Cycle Engines. The engine described in paragraph 8 and illustrated in figures 1 and 4 is a 4-stroke-cycle engine. Four strokes of the piston, with two revolutions of the crankshaft and one revolution of the camshaft, are required for the complete cycle of events. This type of engine is also called a 4-stroke-Otto-cycle engine because it was Dr. N. A. Otto who, in 1876, first applied the principles of this engine. In the 2-stroke-cycle engine, the entire cycle of events (intake, compression, power, and exhaust) takes place in two piston strokes. This is accomplished by combining the four events so that they take place in two instead of four strokes, as explained in (1) and (2) below.

(1) *Two-stroke cycle.* A 2-stroke-cycle engine is shown in figure 7. Every other stroke on this engine is a power stroke. Each time the piston moves down it is on the power stroke. Intake, compression, power, and exhaust still take place, but they are completed in just two strokes. Intake and exhaust ports are cut into the cylinder wall instead of being placed at the top of the combustion chamber as in the 4-stroke-cycle engine. As the piston moves down on its power stroke, it first uncovers the exhaust port to let burned gases escape and then uncovers the intake port to allow a new fuel-air mixture to enter the combustion chamber. Then, on the upward stroke, the piston covers both ports and, at the same time, compresses the new mixture in preparation for ignition and another power stroke. In the engine shown in figure 7, the piston is so shaped that the incoming fuel-air mixture is directed upward, thereby sweeping out ahead of it the burned exhaust gases. Also, there is an inlet into the crankcase through which the fuel-

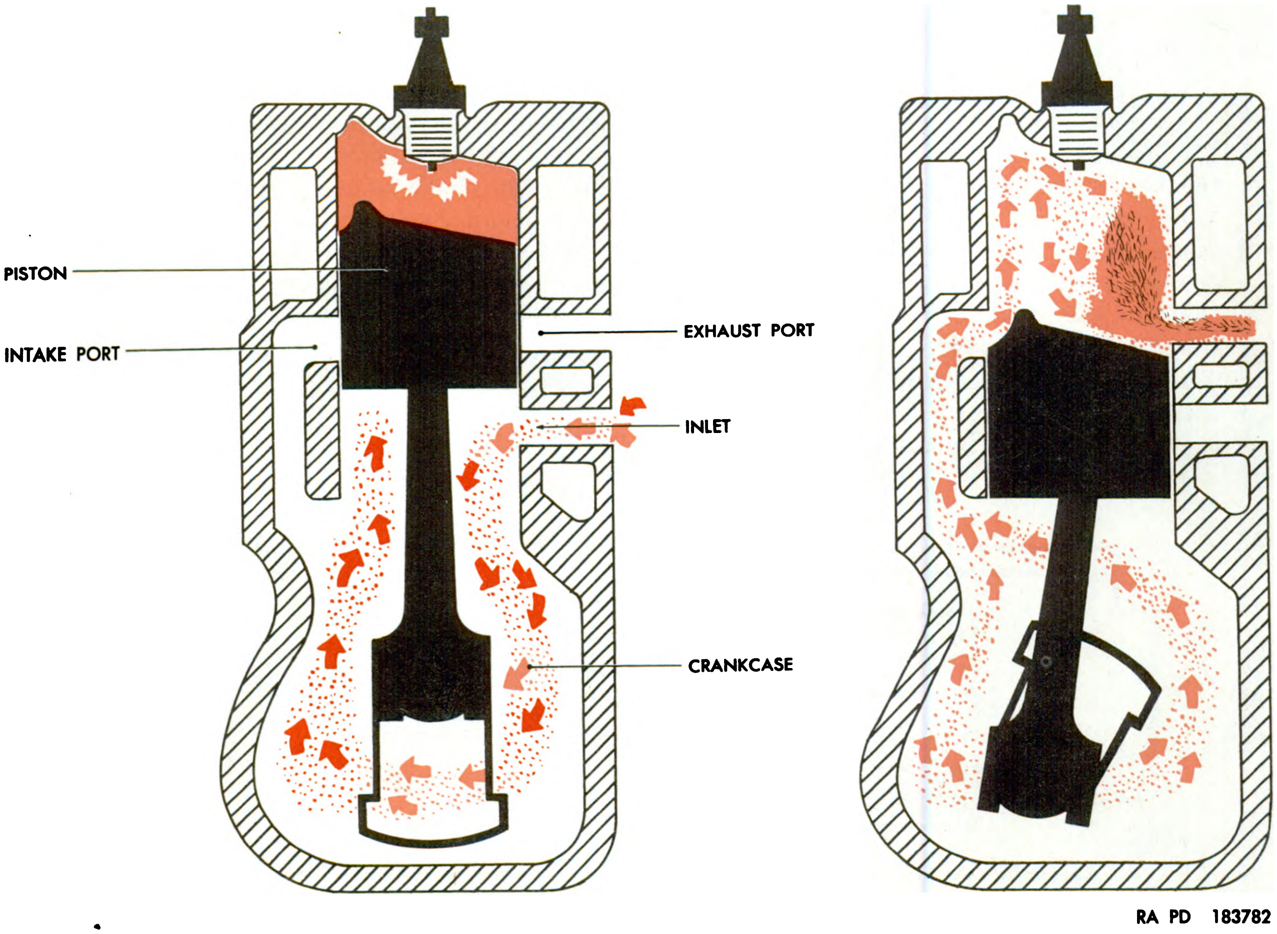

Figure 7. Events in a 2-stroke-cycle, internal combustion engine.

air mixture passes before it enters the cylinder. This inlet is opened as the piston moves upward, but it is sealed off as the piston moves downward on the power stroke. The downward moving piston slightly compresses the mixture in the crankcase, thus giving the mixture sufficient pressure to pass rapidly through the intake port as the piston clears this port. This improves the "sweeping-out," or scavenging, effect of the mixture as it enters and clears the burned gases from the cylinder through the exhaust port.

(2) *Comparison of 2-stroke-cycle and 4-stroke-cycle engines.* It might appear that a 2-stroke-cycle engine could produce twice as much horsepower as a 4-stroke-cycle engine of the same size, operating at the same speed. However, this is not the case. In order to scavenge the burned gases at the end of the power stroke and during the time both the intake and exhaust ports are open, the fresh fuel-air mixture rushes into and through the cylinder. A portion of the fresh fuel-air mixture mingles with the burned gases and is carried out the exhaust port. Also, due to the much shorter period the intake port is open (as compared to the period the intake valve in a 4-stroke-cycle engine is open), a relatively smaller amount of fuel-air mixture is admitted. Hence, with less fuel-air mixture, less power per power stroke is produced as compared to the power produced in a 4-stroke-cycle engine of like size operating at the same speed, and with other conditions being the same. To increase the amount of fuel-air mixture, auxiliary devices are used with 2-stroke-cycle engines to assure delivery of greater amounts of fuel-air mixture into the cylinder. Figure 7 shows one device which utilizes compression in the crankcase ((1) above). Other engines may use a blower or supercharger (par. 58*d*).

c. Diesel Engines. The diesel engine bears the name of Dr. Rudolph Diesel, a German engineer. He is credited with constructing, in 1897, the first successful diesel engine using liquid fuel. His objective was an engine with greater fuel economy than the steam engine, which used only a small percentage of the energy contained in the coal burned under its boilers. Dr. Diesel originally planned to use pulverized coal as fuel, but his first experimental engine in 1893 was a failure. After a second engine also failed, he changed his plan and used liquid fuel. The engine then proved successful.

d. Diesel Engine Compared to Gasoline Engine.

(1) *General mechanical construction.* The diesel engine is mechanically similar to the gasoline engine but is somewhat heavier in construction. Both engine types utilize air, fuel, compression, and ignition. Intake, compression, power, and exhaust occur in the same sequence; arrangements of pistons, connecting rods, and crankshafts are similar. Both are internal combustion engines; that is, they extract energy from a fuel-air mixture by burning the mixture inside the engine.

(2) *Fuel intake and ignition of fuel-air mixture.* In principles of operation, the main difference between gasoline and diesel engines (figs. 8 and 9) is the two different methods of introducing the fuel into the cylinder and of igniting the fuel-air mixture. Fuel and air are mixed together before they enter the cylinder of a gasoline engine. The mixture is compressed by the upstroke of the piston and is ignited within the cylinder by a spark plug. (Devices other than spark plugs, such as "firing tubes," are sometimes utilized.) Air alone enters the cylinder of a diesel engine. The air is compressed by the upstroke of the piston and the diesel fuel is injected into the combustion chamber near the top of the upstroke (compression stroke). The air becomes greatly heated during compression and the diesel fuel ignites and burns as it is injected into the heated air. No spark plug is used in the diesel engine; ignition is by contact of the fuel with the heated air, although "glow plugs" are used in some models of diesel engines to assist in starting. Pressure developed by the compression stroke is much greater in the

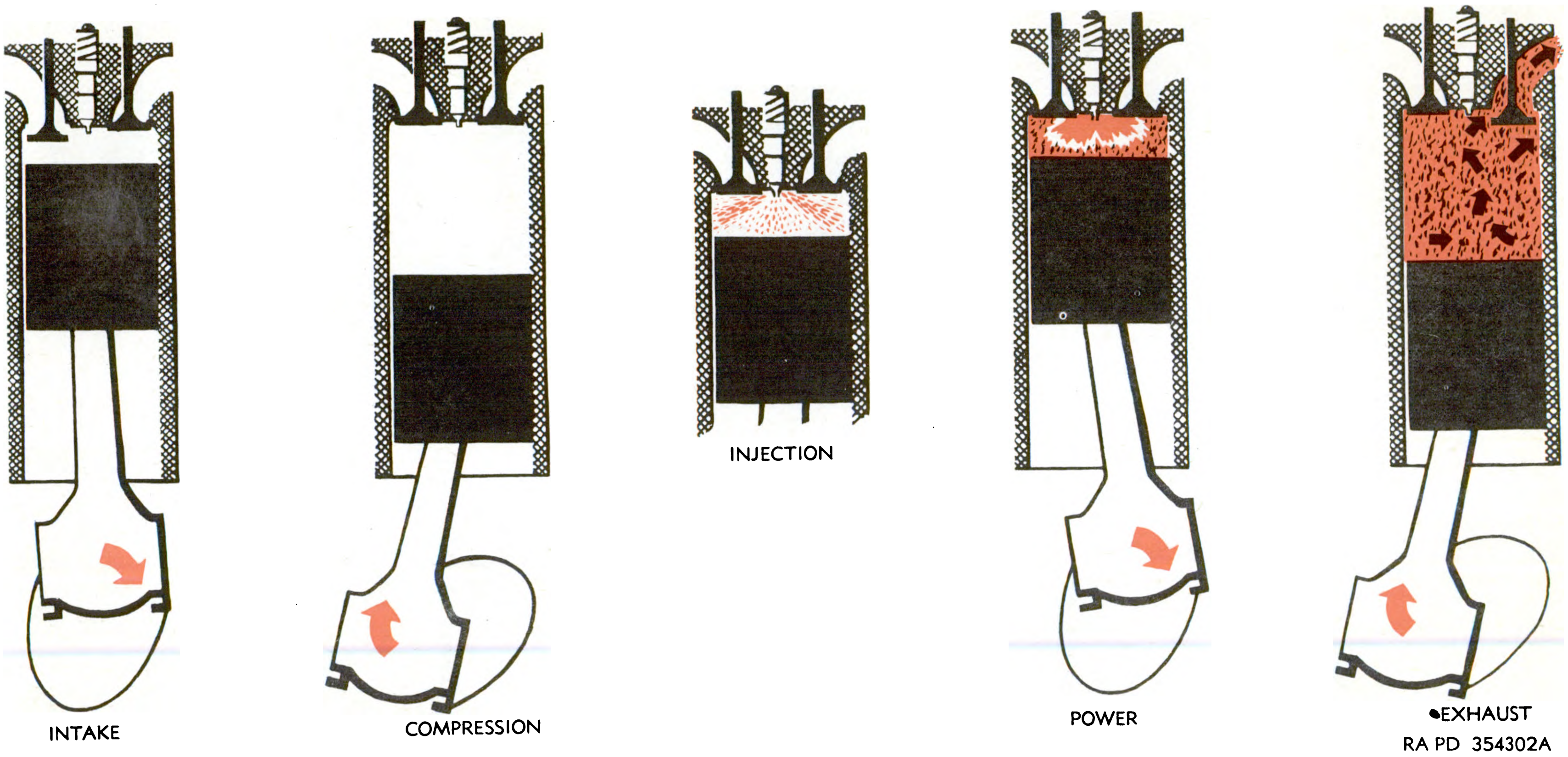
INTAKE
COMPRESSION
INJECTION
POWER
●EXHAUST
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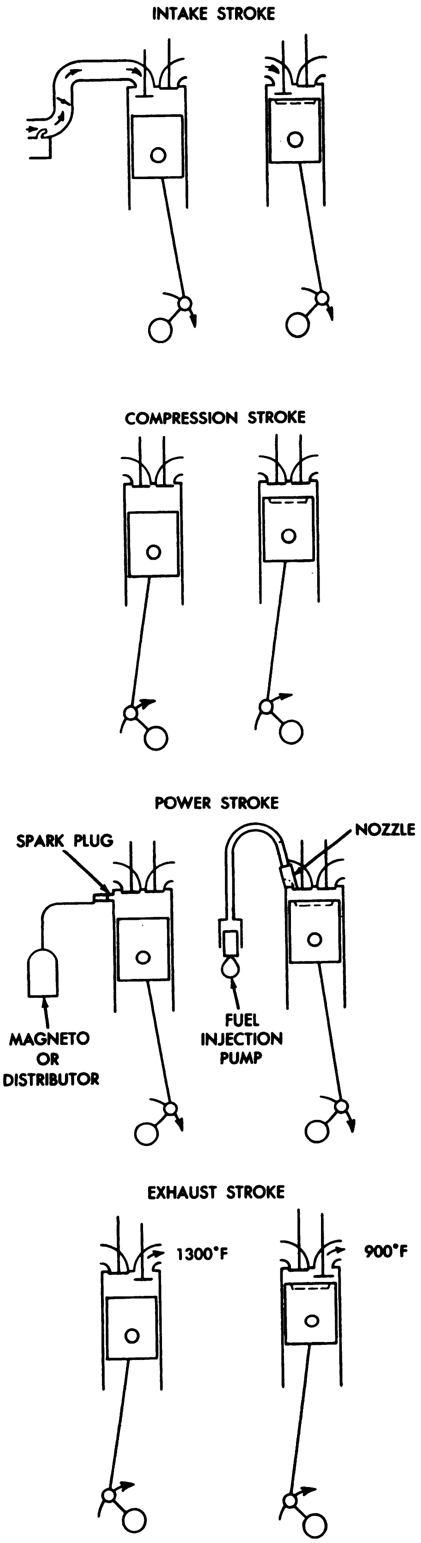
Figure 8. 4-stroke-cycle diesel engine.



GASOLINE

DIESEL

INTAKE STROKE

ON DOWNWARD STROKE OF PISTON, INTAKE VALVE OPENS AND ATMOSPHERIC PRESSURE FORCES AIR THROUGH CARBURETOR WHERE IT PICKS UP A METERED COMBUSTIBLE CHARGE OF FUEL. THE MIXTURE GOES PAST THE THROTTLE VALVE INTO CYLINDER SPACE VACATED BY THE PISTON

ON DOWNWARD STROKE OF PISTON, INTAKE VALVE OPENS AND ATMOSPHERIC PRESSURE FORCES PURE AIR INTO THE CYLINDER SPACE VACATED BY THE PISTON, THERE BEING NO CARBURETOR OR THROTTLE VALVE. CYLINDER FILLS WITH SAME QUANTITY OF AIR, REGARDLESS OF LOAD ON THE ENGINE.

COMPRESSION STROKE

ON UPSTROKE OF PISTON, VALVES ARE CLOSED AND MIXTURE IS COMPRESSED, USUALLY FROM 70 TO 125 PSI, DEPENDING ON COMPRESSION RATIO OF ENGINE.

ON UPSTROKE OF PISTON, VALVES ARE CLOSED AND AIR IS COMPRESSED TO APPROXIMATELY 500 PSI.

POWER STROKE

COMPRESSED FUEL-AIR MIXTURE IS IGNITED BY ELECTRIC SPARK. HEAT OF COMBUSTION CAUSES FORCEFUL EXPANSION OF CYLINDER GASES AGAINST PISTON, RESULTING IN POWER STROKE.

HIGH COMPRESSION PRODUCES HIGH TEMPERATURE FOR SPONTANEOUS IGNITION OF FUEL INJECTED NEAR END OF COMPRESSION STROKE. HEAT OF COMBUSTION EXPANDS CYLINDER GASES AGAINST PISTON, RESULTING IN POWER STROKE.

EXHAUST STROKE

UPSTROKE OF PISTON WITH EXHAUST VALVE OPEN FORCES BURNED GASES OUT, MAKING READY FOR ANOTHER INTAKE STROKE.

UPSTROKE OF PISTON WITH EXHAUST VALVE OPEN FORCES BURNED GASES OUT, MAKING READY FOR ANOTHER INTAKE STROKE.

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Figure 9. Comparison of sequence of events in diesel and gasoline engines.

diesel engine, in which pressures as high as 500 psi are common. For each pound of pressure exerted on the air, there will be a temperature increase of about 2° F. At the top of the compression stroke (when pressure is highest), the temperature in the chamber will be about 1,000° F. This heat ignites the fuel almost as soon as it is injected into the cylinder, and the piston, actuated by the expansion of burning gases, then moves down on the power stroke. In a gasoline engine, the heat from compression is not enough to ignite the fuel-air mixture and a spark plug is therefore necessary.

(3) *Control of speed and power.* The speed and the power output of diesel engines are controlled by the quantity of fuel injected into the cylinder. This is opposed to the common gasoline engine, which controls speed and power output by limiting the amount of air admitted to the carburetor. The difference is that the diesel engine controls the quantity of fuel, whereas the gasoline engine regulates the quantity of air. In the diesel engine, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder on each intake stroke. Because the quantity of air is constant, the amount of fuel injected determines power output and speed. As long as the amount of fuel injected is below the maximum established by the manufacturer in designing the engine, there is always enough air in the cylinder for complete combustion. A device in the carburetor of the gasoline engine controls the amount of air admitted. The amount of air and its velocity, in turn, control the quantity of fuel that is picked up and mixed with air to be admitted to the cylinder. The amount of mixture available for combustion determines power output and speed. It is apparent, therefore, that the controlling factor is the quantity and velocity of air passing through the carburetor.

(4) *Combustion process.* In the diesel engine, there is continuous combustion during the entire length of the power stroke, and pressure resulting from combustion remains approximately constant throughout the stroke. In the gasoline engine, however, combustion is completed while the piston is at the upper part of its travel. This means that the volume of the mixture stays about the same during most of the combustion process. When the piston does move down and the volume increases, there is little additional combustion to maintain pressure. Because of these facts, the cycle of the gasoline engine is often referred to as having *constant-volume* combustion while the diesel cycle is said to have *constant-pressure* combustion.

10. Engine Measurements

a. Bore and Stroke. The size of an engine cylinder is usually indicated in terms of bore and stroke (fig. 10). *Bore* is the diameter of the cylinder. *Stroke* is the distance the piston moves in the cylinder, or the distance between top dead center and bottom dead center. When reference

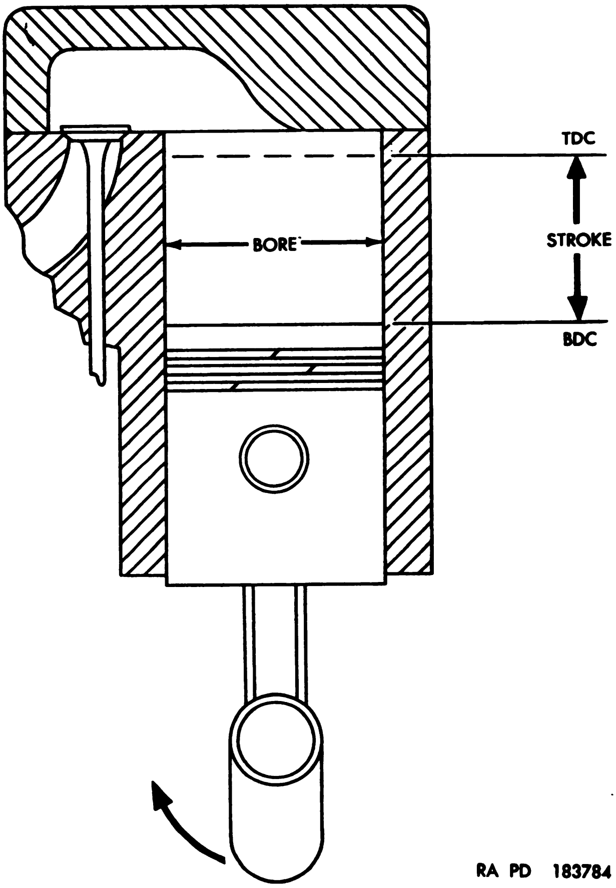

Figure 10. Bore and stroke of an engine cylinder.

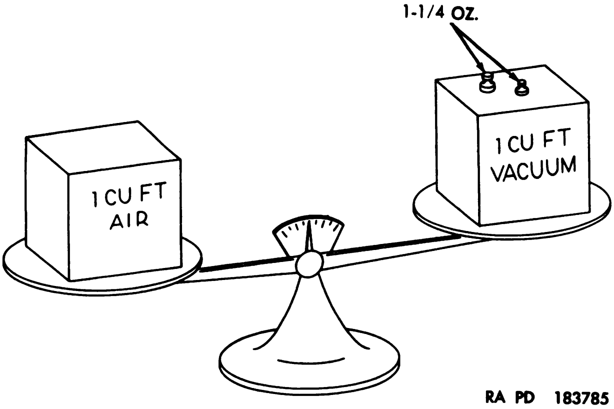

Figure 11. Illustrating the weight of air.

is made to these two measurements, the bore is always given first. For example, a 3⅝ x 4 cylinder means that the cylinder bore, or diameter, is 3⅝ inches and the length of the stroke is 4 inches.

b. Piston Displacement. Piston displacement is the volume of space that the piston displaces as it moves from bottom dead center to top dead center. The volume is figured by multiplying the length of stroke by the area of a circle having the diameter of the cylinder bore. Thus, a ⅝-inch-diameter circle has an area of 10.321 square inches, and therefore, this times 4 inches (length of stroke) equals 41.284 cubic inches, the piston displacement, that is, the number of cubic inches the piston displaces as it moves from bottom dead center to top dead center.

c. Vacuum in Cylinder on Intake Stroke. The piston, in moving down on the intake stroke, produces a partial vacuum in the cylinder. It is this vacuum that is responsible for air rushing in to fill the vacuum. A vacuum can be defined as an absence of air or other substances. It may be hard to think of air as a substance because it does not seem substantial, but it can be felt as a breeze or wind when it is moving.

(1) *The atmosphere.* Air does have weight, as can be proven with a balance scale and two 1-cubic-foot containers (fig. 11). If all air was drawn from one container so that it would be really empty (a vacuum), then it would weigh less than the other container. In fact, to balance the scales, 1¼ ounces would have to be placed on the empty container. At sea level, the weight of the air, pressing downward on the ground, produces a pressure of about 14.7 psi. This amount of pressure means there is a great deal of air above us and there is a great amount of air surrounding the earth. This air, called the *atmosphere*, extends many miles above the earth. The atmosphere is a great ocean of air, and we live at the bottom of it, on the ground.

(2) *Atmospheric pressure.* The miles and miles of air extending above presses downward, or exerts pressure. Ordinarily this pressure is not noticed because we are accustomed to it. If the air was removed from a container and then the container was opened, this pressure would push air back into the container. This might be compared to what happens when an empty bottle is held under water and the cork is removed. The pressure of the water pushes water into the bottle. The higher we go into the air, as for instance when in an airplane, the less pressure is found. The reason for this is that as we ascend there is less air above us; we climb toward the top of the atmosphere. This means there is less air to press down on us and therefore the pressure is less. Six miles above the earth, for example, the pressure is only about 4.4 psi. Returning to earth, the air pressure increases. The nearer earth is approached, or the bottom of the ocean of air, the greater the pressure of the air. At sea level, this pressure is about 14.7 psi ((1) above).

(3) *Vacuum in the cylinder.* When the piston starts to move downward in the cylinder on the intake stroke, it produces a vacuum in the cylinder. If both the intake and exhaust valves were closed, then no substance could enter to fill this vacuum. The cylinder would remain empty. However, at the same time that the piston starts to move down, the intake valve is opened. Now, atmospheric pressure pushes air past the intake valve and into the cylinder. The cylinder therefore becomes filled with air (or with fuel-air mixture in gasoline engines).

d. Volumetric Efficiency. Although the atmosphere exerts considerable pressure and rapidly forces air into the cylinder on the intake stroke, it does take time for the air to flow through the carburetor and past the intake valve. If given enough time, enough air will flow into the cylinder to "fill it up." However, the air is given very little time to do this. For example, when the engine is running at 1,200 rpm, the intake stroke lasts only 0.025 second. In this very brief period, all the air that could enter does not have time to flow into the cylinder. The intake stroke ends too quickly. Nevertheless, engine design has taken this factor into consideration so that good operation will result even at high engine speed.

(1) *Measuring volumetric efficiency.* The measure of the amount of fuel-air mixture that actually enters the cylinder is referred to in terms of *volumetric efficiency.* Volumetric efficiency is the ratio between the amount of fuel-air mixture that actually enters the cylinder and the amount that could enter under ideal conditions. The greater the volumetric efficiency, the greater the amount of fuel-air mixture entering the cylinder. And the greater the amount of fuel-air mixture, the more power produced from the engine cylinder. At low speeds, more fuel-air mixture can get into the cylinder, and therefore the power produced during the power stroke is greater. Volumetric efficiency is high. But at high speeds, the shorter time taken by the intake stroke reduces the amount of fuel-air mixture entering the cylinder. Volumetric efficiency then is lower. In addition, the air is heated as it passes through hot manifolds on its way to the cylinder, and it therefore expands. This further reduces the amount of fuel-air mixture entering the cylinder, and further reduces volumetric efficiency.

(2) *Increasing volumetric efficiency.* Volumetric efficiency is higher at low engine speed because more fuel-air mixture gets into the cylinder ((1) above). Volumetric efficiency can also be improved by use of a blower, or air-compressing, device. On gasoline engines, this device is called a *supercharger.* It raises the air pressure above atmospheric pressure so that the air is pushed harder on its way into the cylinder. The harder push, or higher pressure, insures that more air will enter the cylinder. In a supercharged engine, the volumetric efficiency can run well over 100 percent. Since 100 percent efficiency means that the pressure inside the cylinder equals atmospheric pressure, a volumetric efficiency of more than 100 percent means the pressure inside the cylinder would be greater than atmospheric pressure at the end of the intake stroke. This increased volumetric efficiency increases engine power output. A supercharger is very important on airplane engines because the lowered air pressure (about 4.4 psi at a height of 6 miles) must be greatly increased if engine power output is to be maintained at high altitudes. Also, on 2-stroke-cycle engines, some form of device is required to increase the pressure of the ingoing fuel-air mixture (par. 9*b*).

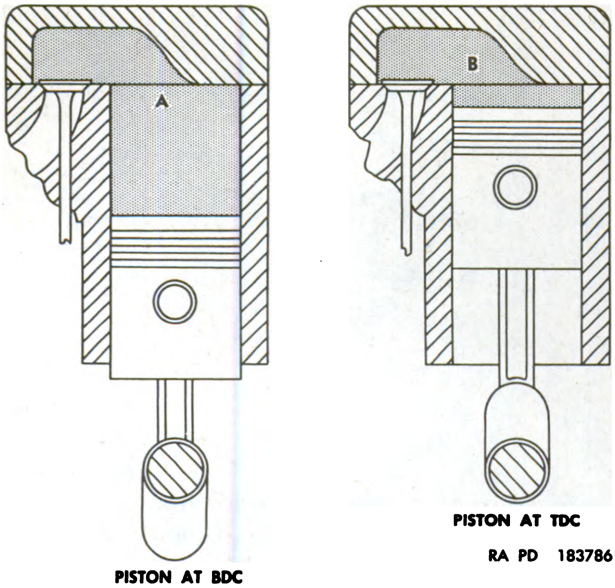

Figure 12. Compression ratio is ratio between "A" and "B."

e. Compression Ratio. The compression ratio of an engine (fig. 12) is the volume in one cylinder with the piston at bottom dead center (displacement volume plus clearance volume) divided by the volume with the piston at top dead center (clearance volume). This figure indicates the actual amount that the air drawn into the cylinder will be compressed. For example, suppose that an engine cylinder has an air volume of 63 cubic inches with the piston at bottom dead center and a volume of 10 cubic inches with the piston at top dead center. This gives a compression ratio of 63 divided by 10 or 6.3:1. That is, the air is compressed from 63 to 10 cubic inches, or to 1/6.3 of its original volume, on the compression stroke.

f. Effect of Increasing Compression Ratio. As compression ratio is increased, the fuel-air mixture drawn into the cylinder is compressed into a smaller space. This means a higher initial pressure at the start of the power stroke. It also means that the burning gases can expand a greater amount. Thus, there are higher pressures for a longer period on the power stroke. More power is obtained with each power stroke. Therefore, increasing compression ratio increases power output of an engine. Racing-car builders machine off cylinder heads so as to reduce the volume of the combustion chambers and thereby increase compression ratios. By this one act, the power output of an engine can be increased several horsepower. One important problem brought about by increasing compression ratios is to find a fuel that will not cause difficulty from detonation. This problem is discussed further in paragraph 49*c*.

11. Timing

In a gasoline engine, the valves must open and close at the proper times with regard to piston position and stroke. In addition, the ignition system must produce the sparks at the spark plugs at the proper time so the power strokes can start. Both valve and ignition system action must be properly timed if good engine performance is to be obtained.

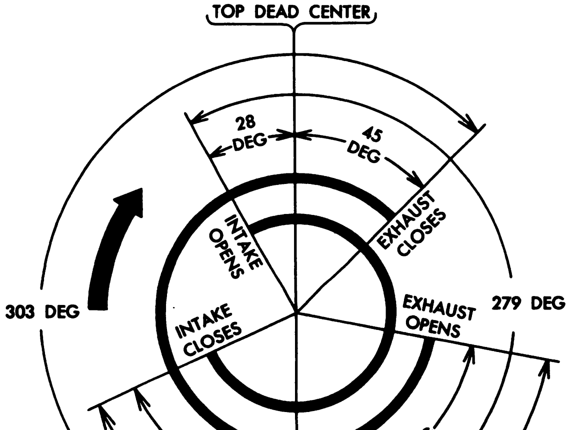

Figure 13. Valve timing diagram on one engine.

a. Valve Timing. A new mixture must be trapped in the cylinder at the proper time during each cycle and, after combustion, the exhaust gases must be allowed to flow out of the cylinder. This means that the intake and exhaust valves must open and close in step with the piston movement. The opening and closing of the valves is controlled by the camshaft. The position of the piston is related to the position of the crankshaft since they are connected by the connecting rod. Thus, the crankshaft and camshaft must be in the proper relationship for correct valve timing. Figure 1 shows one method of driving the camshaft; a gear on the crankshaft drives a gear on the camshaft. These gears are called *timing gears.* The camshaft gear has twice as many teeth as the crankshaft gear (par. 8*e*). Thus, the camshaft turns once for every two crankshaft revolutions. As long as the relationship between the gears is not changed, the timing of the valve action will be in correct relationship to the piston movement. Figure 13 illustrates a valve timing diagram on one engine. Valve timing varies for different engines.

b. Exhaust Valve Timing. The exhaust valve opens before the piston reaches the end of the power stroke so that the pressure remaining in the cylinder will cause the exhaust gases to start rushing from the cylinder. If the valve did not open until the end of the power stroke, then there would be pressure in the cylinder at the start of the exhaust stroke that would impede the upward piston movement. Opening the exhaust valve well before bottom dead center on the power stroke causes some loss of pressure on the piston at the end of the power stroke. However, it does insure better removal of the burned gases which, plus the reduced pressure on the piston at the start of the exhaust stroke, more than balances this small loss.

c. Rock Positions. When the piston is at top dead center the crankshaft can move 15° to 20° without causing the piston to move up or down any perceptible distance. This is one of the two rock positions (fig. 14). When the piston moves up on the exhaust stroke, considerable momentum is imparted to the exhaust gases as they pass out through the exhaust valve port, but if the exhaust valve closes at top dead center, a small amount of the gases will be diluted. Since the piston has

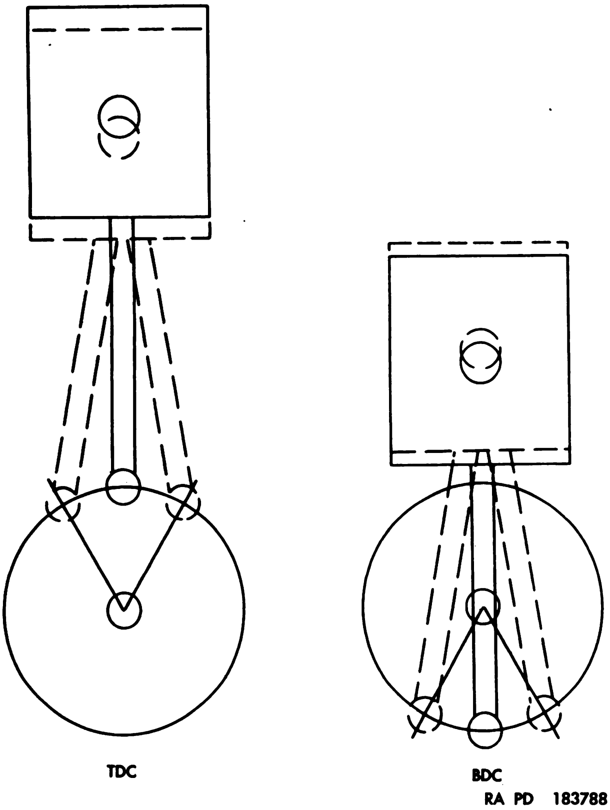

Figure 14. Rock positions.

little downward movement while in the rock position, the exhaust valve can remain open during this period and thereby permit a more complete scavenging of the exhaust gases.

d. Intake Valve Timing. Very little vacuum is produced in the cylinder as the piston passes through the rock position at top dead center. The exhaust gases, however, because of their momentum in passing through the exhaust valve port, produce an air current in the chamber. This air current is sufficient to cause a new mixture to start moving into the cylinder if the intake valve is open. For this reason the intake valve is opened slightly before the piston reaches top dead center. As the piston goes down on the intake stroke, the rapid decrease in pressure in the cylinder enables atmospheric pressure to impart considerable momentum to the incoming mixture. If the piston were to move slowly, the mixture would be able to enter fast enough to keep the pressure in the cylinder equal to that outside. But ordinarily, the piston will be moving so fast that it will reach the end of its downward stroke before a complete change has had time to enter. That is, the pressure in the cylinder will be below that of the atmosphere. The intake valve therefore remains open a number of additional degrees of crankshaft rotation past bottom dead center (or through the lower rock position). This allows additional time for fuel-air mixture to flow into the cylinder.

e. Ignition Timing. Ignition timing refers to the timing of the spark at the spark plug gap with relation to the piston position during the compression and power strokes. Even though the compressed fuel-air mixture burns very rapidly, almost explosively, it does take some time for the mixture to burn and for the pressure increase from combustion to take place. Therefore, it is common for the ignition system to be so timed that the spark occurs before the piston reaches top dead center on the compression stroke. This gives the mixture sufficient time to ignite and start burning. If this time were not provided, that is, if the spark occurred at or after top dead center, then the pressure increase would not keep pace with the piston movement. The piston would be moving down on the power stroke as the mixture started to burn. The pressure, therefore, would not go very high and power would be lost. This power loss is avoided by timing the spark to occur before top dead center.

f. Ignition Advance. At the higher speeds, there is still less time for the fuel-air mixture to ignite and burn. In order to compensate for this, and thereby avoid power loss, the ignition system includes an advance mechanism that functions on speed. As engine speed increases, the advance mechanism causes the spark to occur earlier in the cycle. Thus, at high speed, the spark may occur as much as 30° before top dead center on the compression stroke. This means that the fuel-air mixture is ignited and starts to burn well before the power stroke actually starts. However, the piston is up over top dead center and moving down on the power stroke before the pressure rises to any great extent. This extra time gives the mixture ample time to burn well and deliver maximum push to the downward-moving piston. On most distributors, there is also a vacuum-advance mechanism which functions on intake-manifold vacuum. At part throttle, there is a partial vacuum in the intake manifold, and less fuel-air mixture is getting into the cylinder. With less fuel-air mixture, the mixture is less highly compressed and burns more slowly. Therefore, the vacuum-advance mechanism provides a spark advance which gives the mixture ample time to burn and increase pressure in the cylinder in the early part of the power stroke. These two advance mechanisms are discussed in detail in paragraph 149*f*.

12. Engine Output

Engines vary in size and output. To compare engines, compare not only their size, but also the work they can do. These functions are explained in *a* through *j* below.

a. Work. Work is the movement of a body against an opposing force. When a weight is lifted from the ground, work is done on the weight. It is moved upward against the force of gravity. When a tank pushes over a tree, it does work on the tree as it forces it to the ground. If a 1-pound weight is lifted one foot, one *foot-pound* of work is done.

b. Energy. Energy is the ability to do work. As the speed of a tank is increased, the energy of movement of the tank is increased. It can thereby knock over a tree more easily. The higher a weight is lifted from the ground, the more energy is stored in the weight. Then, when it falls, it will strike the ground harder; that is, it will do more work on the ground. Suppose a stake is being driven in the ground. The greater the distance the weight falls, the more work it does on the stake and the farther it drives it into the ground.

c. Power. Power is the rate of work. It takes more power to work fast than to work slowly. Engines are rated in terms of the amount of work they can do per minute. A large engine that can do more work per minute is more powerful than a small engine which cannot work so hard. The work capacity of engines is measured in *horsepower*. A horsepower is a definite amount of power. Actually, it is the amount of power that an average horse was found to develop when working hard in tests made many years ago at the time steam engines were being developed. It was found that an average horse could lift a weight of 200 pounds a distance of 165 feet in 1 minute. The amount of work involved here is 33,000 foot-pounds (165 times 200). If 100 pounds were lifted 330 feet, or if 330 pounds were lifted 100 feet, the amount of work would be the same, 33,000 foot-pounds. When this amount of work is done in 1 minute, then 1 horsepower is required. If it took 2 minutes to do this amount of work, then 16,500 foot-pounds per minute, or ½ hp, would be required. Or, if 33,000 foot-pounds of work were done in ½ minute, then 66,000 foot-pounds per minute, or 2 hp, would be required.

d. Prony Brake. A prony brake may be used to measure the actual horsepower that an engine can deliver. This device usually makes use of a series of wooden blocks fitted around a special flywheel that is driven by the engine (fig. 15). A tightening device is arranged so the blocks can be tightened on the flywheel. In addition, an arm is attached to this tightening device and one end of the arm rests on a scale. In operation, the wooden blocks are tightened on the flywheel. This loads up the engine and works it harder. Also, the pressure on the blocks tends to cause the arm to turn so that force is exerted on the scales. The length of the arm times the force exerted on the scales gives the engine torque in pound-feet (*f* below). The results of the prony brake test can be converted into brake horsepower by using the formula:

$$Bhp = \frac{2\,\pi\,lnw}{33,000}$$

where l is length of the arm in feet, n is the speed in rpm, and w is the load in pounds on the scale. For example, suppose the arm is 3 feet long, the load on the scale is 50 pounds, and the speed is 1,000 rpm. Substituting in the formula gives:

$$Bhp = \frac{2 \times 3.1416 \times 3 \times 1,000 \times 50}{33,000} = 28.56 \text{ brake horsepower}$$

e. Dynamometer. The dynamometer is essentially a dynamo of a special type which can be driven by an engine. This special dynamo can absorb all the power the engine can produce and indicate this power on dials or gages. Although the dynamometer is more complicated than a prony brake, it is generally considered to be more flexible and accurate. In addition to measuring

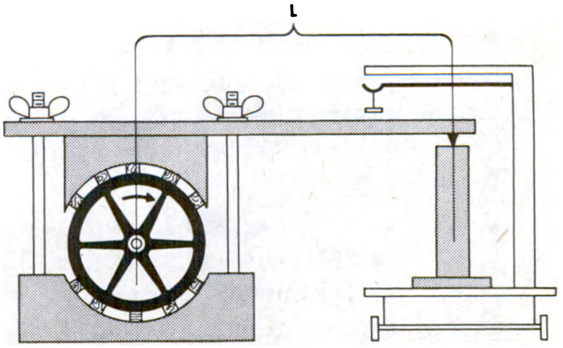

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Figure 15. Simplified drawing of a prony brake.

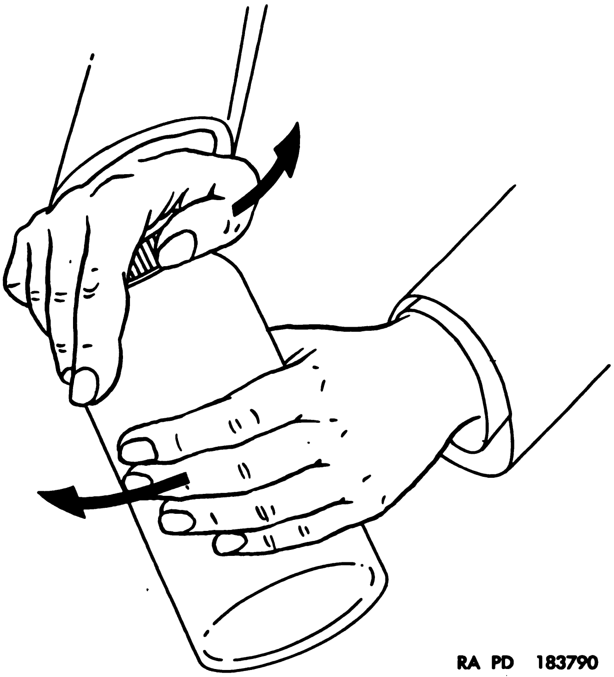
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Figure 16. Applying twisting effort, or torque, on can lid.

engine power output, the dynamometer can also be used to drive the engine for purposes of measuring the friction of the engine itself or of the various accessories.

f. Torque Effect.

(1) Torque is twisting, or turning, effort. When the lid on a jar is loosened, a twisting force, or torque, is applied to it (fig. 16). Torque is measured in *pound-feet* (not to be confused with work, which is measured in foot-pounds). For instance, suppose a wrench is used to tighten a nut on a stud (fig. 17). If the handle of the wrench were 1-foot long and a 10-pound force is put on its end, 10 pound-feet of torque would be applied on the nut. If the handle were 2 feet long and 10-pound force is put on its end, 20 pound-feet of torque would be applied. Torque can be converted into work with the formula

ft-lb (work) $= 2\pi n$ x lb-ft (torque) $=$ 6.2832 n x lb-ft where n is the speed in revolutions per minute. For example, if an engine were checked on a prony brake and found to be delivering 100 pound-feet torque at 1,000 rpm then it would be doing 628,320 foot-pounds of work every minute. This can be converted into horsepower by dividing it by 33,000 (*d* above). An illustration of a torque wrench in use is shown in figure 18.

(2) The engine exerts torque through gears and shafts connected to the wheels so that the wheels turn and the vehicle moves. The amount of torque that an engine produces varies with engine speed (fig. 19). Note that torque increases and then, at an intermediate speed, falls off. The reason for this variation is that, with increasing speed, the engine is turning faster and is thus capable of supplying a greater twisting effort, or torque. However, with further speed increases, volumetric efficiency falls off. Less fuel-air mixture gets to the cylin-

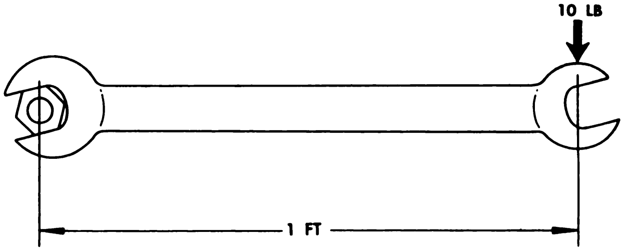

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Figure 17. Applying torque with a wrench on a nut.

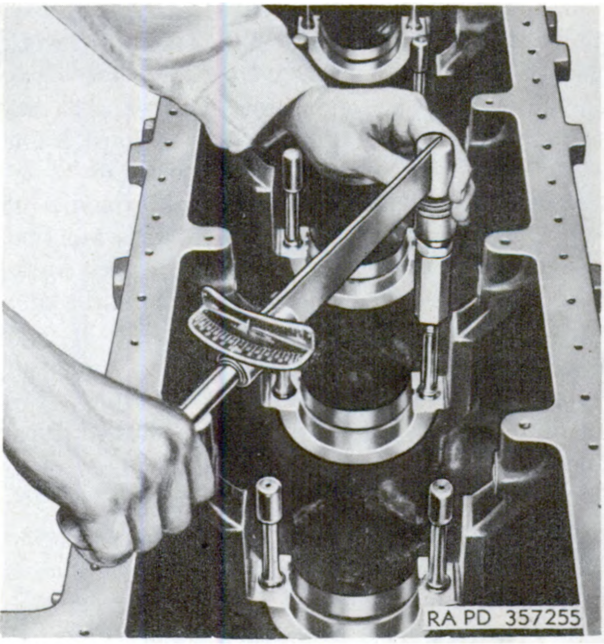
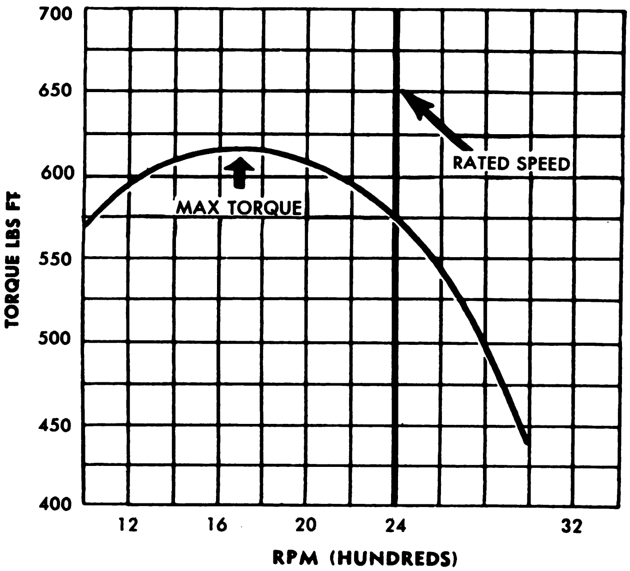


Figure 18. Torque wrench in use, tightening main bearing studs of an engine.



RA PD 368816

Figure 19. Relationship between torque and speed.

ders each intake stroke and thus the power strokes are not as powerful; torque falls off.

g. Torque-Horsepower-Speed (Rpm) Relationship.

(1) Figure 20 shows the comparison between the horsepower and torque of an engine. Torque increases with speed (up to rated speed) as shown in figure 19. Horsepower also shows a change with speed, and this is more marked than with torque. Horsepower is directly related to both torque and to speed. When both torque and speed are on the increase, as in the speed range of 1,200 to 1,600 rpm, then horsepower goes up sharply. When torque reaches maximum and then begins to taper off, the horsepower curve starts to drop. Finally, in the higher speed ranges, where torque falls off sharply, horsepower also falls off. The horsepower formula ($Hp=\frac{2\pi lw}{33,000}$) given in *d* above shows that horsepower depends on both speed and torque, since torque equals *lw* and *n* is speed. Substituting in the formula and dividing 2π (or 6.2832) into 33,000 gives

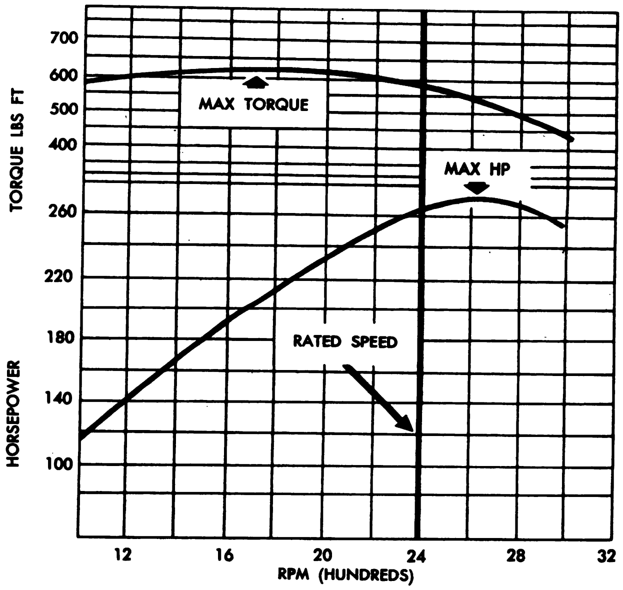
$$Hp=\frac{\text{torque x rpm}}{5,252}$$

which shows the relationship between horsepower, torque, and speed more directly.

(2) A *rated speed* is indicated in figures 19 and 20. This is the speed at which the governor is usually set in military vehicles. The rated speed is selected because, at higher engine speeds, wear on the engine increases rapidly and a disproportionate amount of fuel is used (par. 72). Overspeeding, or driving the engine above rated speed, allows but a slight increase of horsepower.

h. Gross and Net Horsepower. The gross horsepower of an engine is the amount of power the engine delivers after it has been stripped of muffler, fan, generator, pump, and other accessories that require power to operate. Net horsepower is the power remaining and actually available to drive the vehicle. Net horsepower is the power available at the flywheel after the accessories have detracted from the gross horsepower.

i. Indicated Horsepower. Indicated horsepower is the horsepower actually developed inside the engine cylinders. It is called "indicated" horsepower because an indicating device is required to measure this horsepower. This device measures the pressures developed in the engine cylinders and, by a series of steps, translates this



RA PD 184175

Figure 20. Relationship between torque and horsepower.

data into indicated horsepower. Indicated horsepower is always considerably greater than horsepower delivered by the engine because power is lost from the engine in a number of ways (friction, heat-loss, etc.) as explained in paragraph 13.

j. SAE Horsepower. The Society of Automotive Engineers (SAE) developed a simplified method of calculating horsepower, based on engine dimensions. This rating was used only for commercial licensing of vehicles. The formula is:

$$\text{Hp}=\frac{DN}{2.5}$$

where D is the cylinder diameter and N is the number of cylinders.

13. Engine Efficiency

The term *efficiency* means the relationship between results obtained and the effort required to obtain those results. It is expressed as: efficiency $=\frac{\text{output}}{\text{input}}$. Suppose, for example, a set of pulleys were used to raise a 450-pound weight 2 feet and this required a 100-pound pull for 10 feet (fig. 21). It would take 1,000 foot-pounds to get out 900 foot-pounds. The ratio would be $\frac{900}{1,000}$, or 0.90. In other words, the efficiency of the pulleys would be 90 percent. There was a loss of 10 percent of the work put in. The system of pulleys shows a loss (or is only 90 percent efficient) because of friction. No machine or engine is 100 percent efficient; all lose energy, as explained in *a*, *b*, and *c* below.

a. Friction Loss. Friction is source of energy loss in any mechanical system. If a heavy plank is dragged across a rough floor, it offers some resistance to the movement. This resistance to movement would be less if the plank and floor were polished smooth. Resistance would be still less if the plank floated in water. This resistance to movement is called *friction*. Friction can be visualized as being caused by tiny irregularities, or high points, on the surfaces of the moving objects. These catch on each other and particles are torn off. All this requires force to overcome. If the plank and floor are made smooth, then the projecting points are much smaller and have less tendency to catch and tear off. Therefore, less force is required to pull the plank across the floor. And if the plank is floated in water, the surfaces can no longer rub against each other. There is, however, still some friction in the liquid. In the engine, friction occurs at all moving parts, even though the parts are, in effect, floated in films of oil. More on the subject of friction will be found in chapter 8 on engine lubrication systems.

b. Mechanical Efficiency. The mechanical efficiency of the engine is the relationship between the power produced in the engine cylinders (indicated horsepower) and the power delivered by the engine (brake horsepower). Internal engine losses from friction and other factors always prevent brake horsepower from equaling indicated horsepower. A typical engine, for example, might develop 200 indicated horsepower as

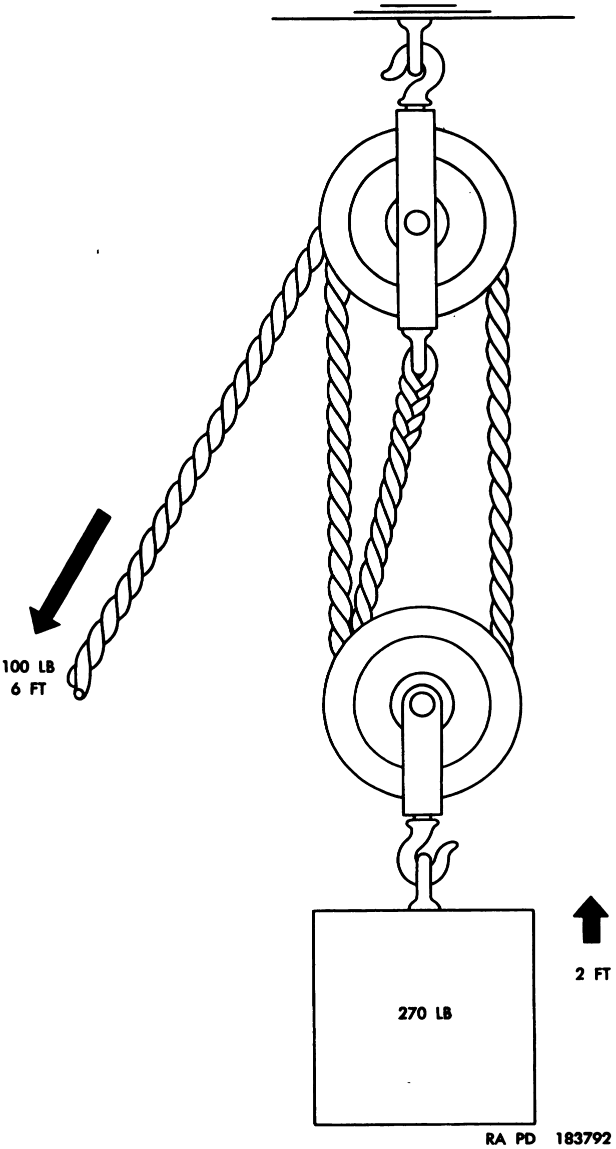


Figure 21. System of pulley in which 1,000 foot-pounds must be expended to realize 900 foot-pounds of work.

against an actual brake horsepower of 180. This engine would have a mechanical efficiency of:

$$\frac{\text{Brake horsepower}}{\text{Indicated horsepower}}=\frac{180}{200}=90 \text{ percent}$$

c. Thermal Efficiency.

(1) Thermal efficiency is the relationship between the heat energy in the fuel and the engine power output (thermal means of or pertaining to heat). The term *thermal efficiency* relates the heat energy of the fuel and the work output. The heat energy is the amount of heat the fuel will produce as it burns. Much of this heat is lost to the cylinder walls and cooling system. Still more is lost in the hot exhaust gases as they pass out of the cylinder. This heat that is lost cannot do anything to cause the engine to produce power. Therefore, only a relatively small part of the heat in the burning fuel can contribute anything toward pushing down on the pistons and thereby causing the engine to produce power. In actual practice, because of the great amount of heat lost to the cooling water, lubricating oil, and in the exhaust gases, thermal efficiency may be as low as 20 percent. In other words, as much as 80 percent of the energy in the fuel is lost. However, the remaining 20 percent is sufficient to operate the engine normally. Practical limitations prevent thermal efficiencies of much above 25 percent.

(2) The overall thermal efficiency of an engine is the relationship between the fuel input and the power output. This relationship is commonly expressed in heat units called *British thermal units* (Btu). One Btu is equal to 778 ft-lb of work; therefore, the horsepower output of an engine can be readily converted into Btu per unit of time. The source of power in an engine is fuel, and the Btu content of regularly-used fuels has been determined by laboratory analysis:

$$\text{Thermal efficiency}=\frac{\text{power output in Btu}}{\text{fuel input in Btu}}$$

Example. An engine delivers 85 bhp for a period of 1 hour and in that time consumes 50 pounds (approx 7½ gals) of gasoline. Assuming that the gasoline has a value of 18,800 Btu per lb, we find the thermal efficiency of the engine:

Power delivered by engine is 85 bhp for 1 hour, or 85 hp-hours

$$1 \text{ hp-hour}=\frac{33{,}000 \text{ ft-lb per min}\times 60 \text{ min}}{778 \text{ ft-lb per Btu}}$$

$$=2{,}545 \text{ Btu}$$

$85 \text{ bhp}\times 2{,}545 \text{ Btu}=216{,}325$ Btu output

$50 \text{ lb}\times 18{,}800 \text{ Btu per lb}=940{,}000$ Btu input per hour

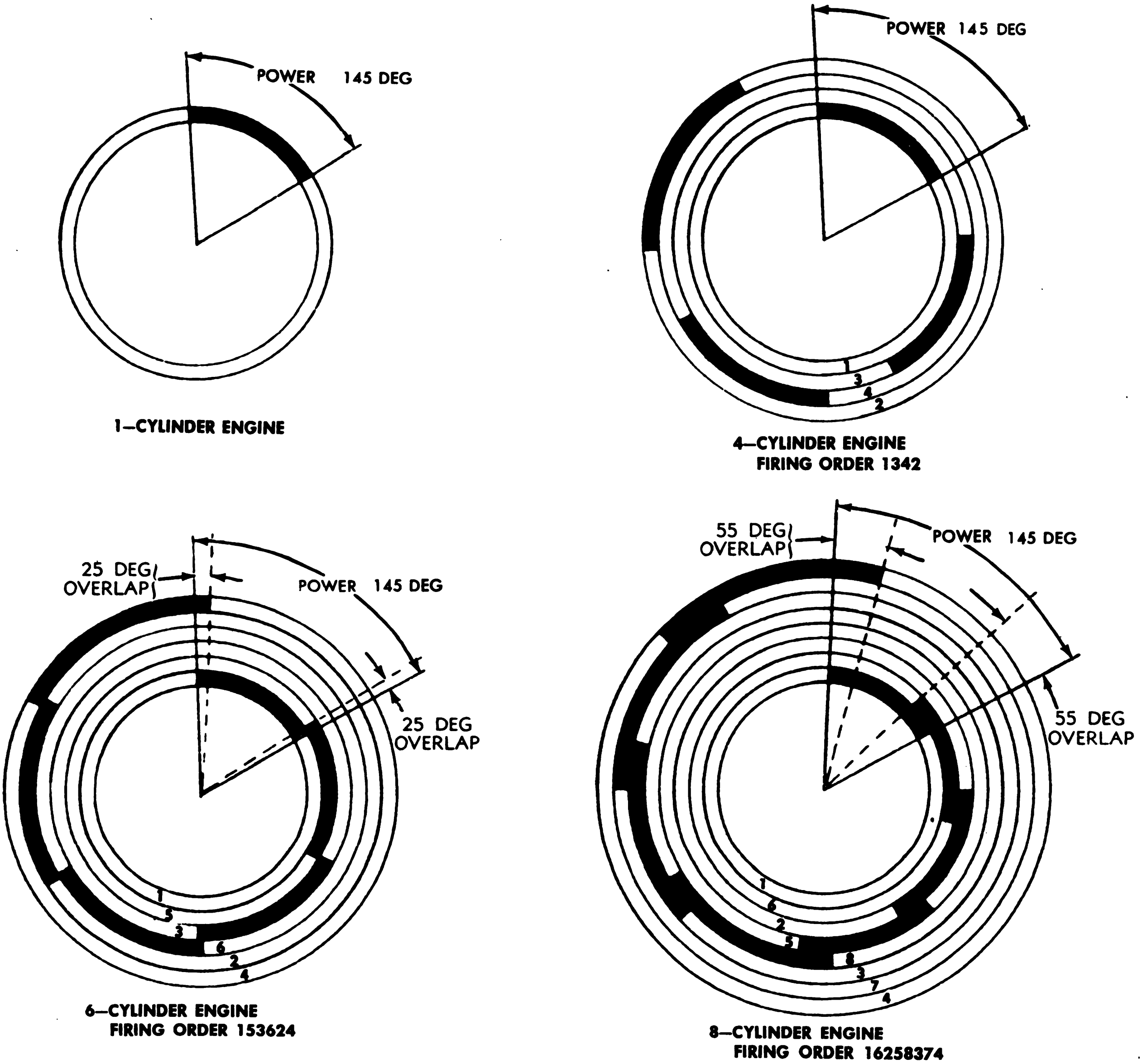
$$\text{Overall thermal efficiency}=\frac{216{,}325}{940{,}000}$$

$$=0.230, \text{ or } 23 \text{ percent}$$

14. Advantages of Multicylinder Engines

a. Power Increase. In early automotive vehicles, 1-cylinder and some 3-cylinder engines were used, but the many advantages of a larger number of cylinders soon led to the adoption of 4-, 6-, 8-, 12-, and 16-cylinder engines. Although the power stroke of each piston theoretically continues for 180° of crankshaft rotation, best results can be obtained if the exhaust valve is opened when the power stroke has completed about four-fifths of its travel. Therefore, the period that power is delivered during 720° of crankshaft rotation, or one 4-stroke cycle, will be 145° multiplied by the number of cylinders in the engine. If an engine has two cylinders, power will be transmitted for 290° of the 720° of travel necessary to complete the four events of the cycle. The flywheel (par. 29) must supply power for the remaining 430° of crankshaft travel.

b. Power Overlap. As cylinders are added to an engine, each one must complete the four steps of the cycle during two revolutions of the crankshaft. The number of power impulses for each revolution also increases, producing smoother operation. If there are more than four cylinders, the power strokes overlap as shown in figure 22. The length of overlap increases with the number of cylinders. The diagram for the 6-cylinder engine shows a new power stroke starting each 120° of crankshaft rotation and lasting for four-fifths of a stroke, or 145°. This provides an overlap of 25°. In the 8-cylinder engine, a power stroke starts every 90° and continues for 145°, resulting in a 55° overlap of power. Because the cylinders fire at regular intervals, the power overlap will



1—CYLINDER ENGINE

4—CYLINDER ENGINE
FIRING ORDER 1342

6—CYLINDER ENGINE
FIRING ORDER 153624

8—CYLINDER ENGINE
FIRING ORDER 16258374

NOTE:—THE CIRCLES SHOWN ABOVE REPRESENT 720 DEG NOT 360 DEG BECAUSE THE CRANKSHAFT MUST ROTATE THROUGH 720 DEG TO COMPLETE THE CYCLE ONCE FOR ALL CYLINDERS

RA PD 354307B

Figure 22. Power in 1-, 4-, 6-, and 8-cylinder engines.

be the same regardless of firing order, and will apply to either in-line or V-type engines.

15. Classification of Engines

Automotive engines may be classified according to the type of fuel they use, type of cooling employed, or valve and cylinder arrangement. They all operate on the internal combustion principle, and the application of basic principles of contruction to particular needs or systems of manufacture has caused certain designs to be recognized as conventional. The most common method of classification is by type of fuel used, that is, whether the engine burns gasoline or diesel fuel. This method is covered in chapter 3, so only classification by type of cooling valve arrangement and by cylinder arrangement will be discussed here.

a. Cooling. Engines are classified as to whether they are air- or liquid-cooled. All engines are cooled by air to some extent, but air-cooled engines are those in which air is the only external cooling medium. Lubricating oil and

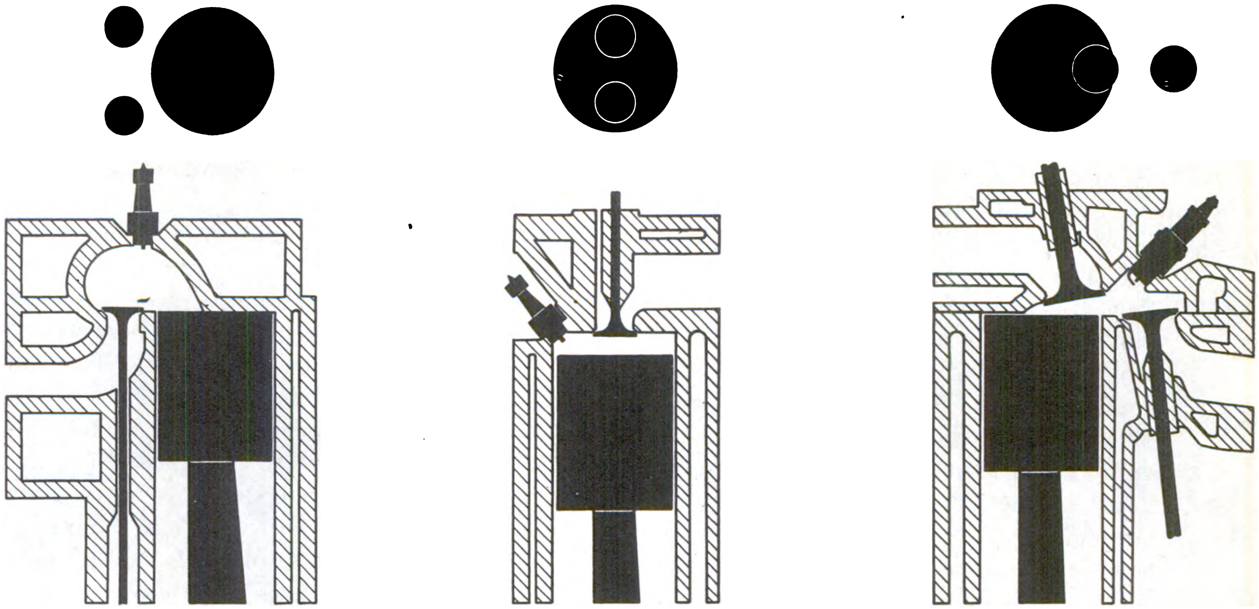


Figure 23. **L**-, **I**-, *and* **F**-*head valve arrangements.*

fuel helps somewhat to cool all engines, but there must be an additional external means of dissipating the heat absorbed by the engine during the power stroke.

(1) *Air-cooled.* Although air-cooled engines are not normally used in passenger cars and commercial trucks, they are used extensively in military vehicles as well as in aircraft. This type of engine is used where there must be an economy of space and weight. It does not require a radiator, water jacket, coolant, or a pump to circulate the coolant. The cylinders are cooled by conducting the heat to metal fins on the outside of the cylinder wall and head. To effect the cooling, air is circulated between the fins. When possible, the engine is installed so that it is exposed to the air stream of the vehicle; the baffles direct the air to the fins. If the engine cannot be mounted in the air stream, a fan is employed to force the air through the baffles.

(2) *Water-cooled.* Water-cooled engines require a water jacket to hold the coolant around the valve ports, combustion chambers, and cylinders; a radiator to dissipate the heat from the coolant to the surrounding air; and a pump to circulate the coolant through the engine. Water-cooled engines also require a fan to pass air through the radiator because the speed of the vehicle does not always force enough air through the radiator to provide proper dissipation of heat.

b. Valve Arrangement. Engines may be classified according to the position of the intake and exhaust valves, that is, whether they are in the cylinder block or in the cylinder head. Various arrangements have been used, but the most common are **L**-head, **I**-head, and **F**-head (fig. 23). The letter designation is used because the shape of the combustion chamber resembles the form of the letter identifying it.

(1) **L**-*head.* In the **L**-head engines both valves are placed in the block on the same side of the cylinder. The valve-operating mechanism is located directly below the valves, and one camshaft actuates both the intake and exhaust valves. This type has supplanted the **T**-head, in which both valves were in the block but on opposite sides of the cylinder. The disadvantage of the **T**-head was that it required two complete valve-operating mechanisms.

(2) **I**-*head.* Engines using the **I**-head construction are commonly called *valve-in-head* or *overhead valve* engines, because the valves are mounted in the cylinder

head above the cylinder. This arrangement requires a tappet, a push rod, and a rocker arm above the cylinder to reverse the direction of valve movement, but only one camshaft is required for both valves. Some overhead valve engines make use of an overhead camshaft. This arrangement eliminates the long linkage between the camshaft and valve.

(3) F-*head.* In the F-head engine, the intake valves normally are located in the head, while the exhaust valves are located in the engine block. This arrangement combines, in effect, the L-head and the I-head valve arrangements. The valves in the head are actuated from the camshaft through tappets, push rods, and rocker arms (I-head arrangement), while the valves in the block are actuated directly from the camshaft by tappets (L-head arrangement).

c. Cylinder Arrangment. Automotive engines also vary in the arrangement of cylinders in the block, depending on the engine use. Cylinder arrangement in liquid-cooled engines is usually in-line or V-type; in air-cooled engines, it is V-type, radial, or horizontal-opposed.

(1) *In-line.* The vertical in-line cylinder arrangement is one of the most common used types. All the cylinders are cast or assembled in a straight line above a common crankshaft which is immediately below the cylinders. A variation is the inverted in-line type.

(2) V-*type.* In the V-type engine, two "banks" of in-line cylinders are mounted in a V-shape above a common crankshaft. This type is designated by the number of degrees in the angle between the banks of cylinders. Usually the angle of the V is 90° for 8-cylinder engines; 75°, 60°, or 45° for 12-cylinder engines; and 45° or 135° for 16-cylinder engines. Crankshafts for V-type engines generally have only half as many throws as there are cylinders, as two connecting rods (one from each bank) are connected to each throw.

(3) *Radial.* The radial engine has cylinders placed in a circle around the crankshaft. The crankshaft has only one throw, and one piston is connected to this throw by a *master rod.* The connecting rods from the others pistons are fastened to the master rod, making the power flow first to the master rod and then to the crankshaft. The result is the same as if each rod were connected directly to the crankshaft. High-powered radial engines may have two rows of cylinders in which each row operates on its own throw of the crankshaft.

(4) *Horizontal-opposed.* The horizontal-opposed engine has its cylinders laid on their sides in two rows, with the crankshaft in the center. Because of its low overall height, much less headroom is required for mounting the engine. It can be put under the body of a bus, for example, or can be so mounted in a tank as to provide additional interior space in the tank. This engine is often called a *pancake* engine, because it is relatively flat like a pancake.

(5) *Horizontal-opposed with vertical crankshaft.* In this engine, the cylinders are horizontal and opposed to each other, but the crankshaft is set vertically. This is the same type of engine mentioned in (4) above, except that the engine has been set up on end so that the crankshaft is vertical rather than horizontal.

CHAPTER 4

CONSTRUCTION OF ENGINES

16. General

This chapter discusses the basic components of engines. Because many of the parts of in-line, horizontal-opposed, and V-type engines are similar, they may be described together. Certain components of radial engines, however, require special descriptions because they differ considerably from the components used in other engines. For example, the crankcases, camshafts, and gear trains used in radial engines have very little resemblance to the crankcases, camshafts, and gear trains used in in-line engines. In addition, the cylinders of radial and other air-cooled engines differ considerably from cylinders in liquid-cooled engines. Separate explanations of these differing components are given in this chapter. The cooling, fuel, ignition, and lubrication systems and their component parts are described in other chapters.

17. Cylinder Block, Liquid-Cooled Engine

a. Cylinder blocks are used only in liquid-cooled engines, whether they are in-line, horizontal-opposed, or V-type. Cylinder blocks were formerly made of gray cast iron, but the wearing qualities of this metal were not adequate. The material now used in cylinder blocks is a special iron alloy containing nickel, chromium, and molybdenum. The cylinder block of an engine contains the cylinders in which the pistons move, the valve ports (in L-head engines), and the passages through which the coolant flows. It also forms the upper part of the crankcase and, as such, acts as the base of the engine (fig. 24).

b. The cylinders and crankcase are cast enbloc, that is, in one piece called the *cylinder block*. The advantages of the enbloc method are so many that it has become almost universal. Casting cylinders enbloc produces more compact, shorter, and more rigid construction at less cost than casting cylinders singly or in pairs; assembly is simplified, and valve-operating mechanisms are easier to inclose.

c. The cylinders of a liquid-cooled engine are surrounded by jackets through which the liquid circulates. These jackets are cast integral with the cylinder block, (fig. 24). Communicating passages permit the coolant to circulate around the cylinders and through the head.

d. Cylinders must be absolutely round and true, and the surfaces must be highly finished. These surfaces are obtained in manufacturing by boring, grinding, and/or honing (in that order), and the final result is a precision finish which offers little friction and assures a uniform seal between cylinder and piston rings.

e. Cylinder liners, or sleeves, are becoming more common in large motor-vehicle engines. Liners are of two types and are made of alloys specially treated to give better wearing qualities. The "wet"-type liner comes in direct contact with the coolant and is sealed at the top and bottom by a rubber sealing ring; the "dry"-type liner does not contact the coolant directly. Liners have two advantages; they usually wear longer and, after they have been worn beyond the maximum oversize, can be replaced, avoiding the replacement of the entire block.

18. Cylinder Head

In liquid-cooled engines, the cylinder head (fig. 25), a separate casting which contains the combustion chambers, is bolted to the top of the cylinder block to close the upper ends of the cylinders. It contains passages which match those of the cylinder block and allow the coolant to circulate in the head. It has tapped holes in the combustion chambers into which the spark plugs are screwed. To retain compression in the cylinder, a metal or metal-asbestos cylinder-head gasket is placed between the head and the block. Holes are cut in this gasket for the bolts or studs holding the cylinder head to the block, for the passage of coolant from the block to the head, and for the combustion chambers. The cylinder heads of overhead-valve engines also contain and support the valves, valve

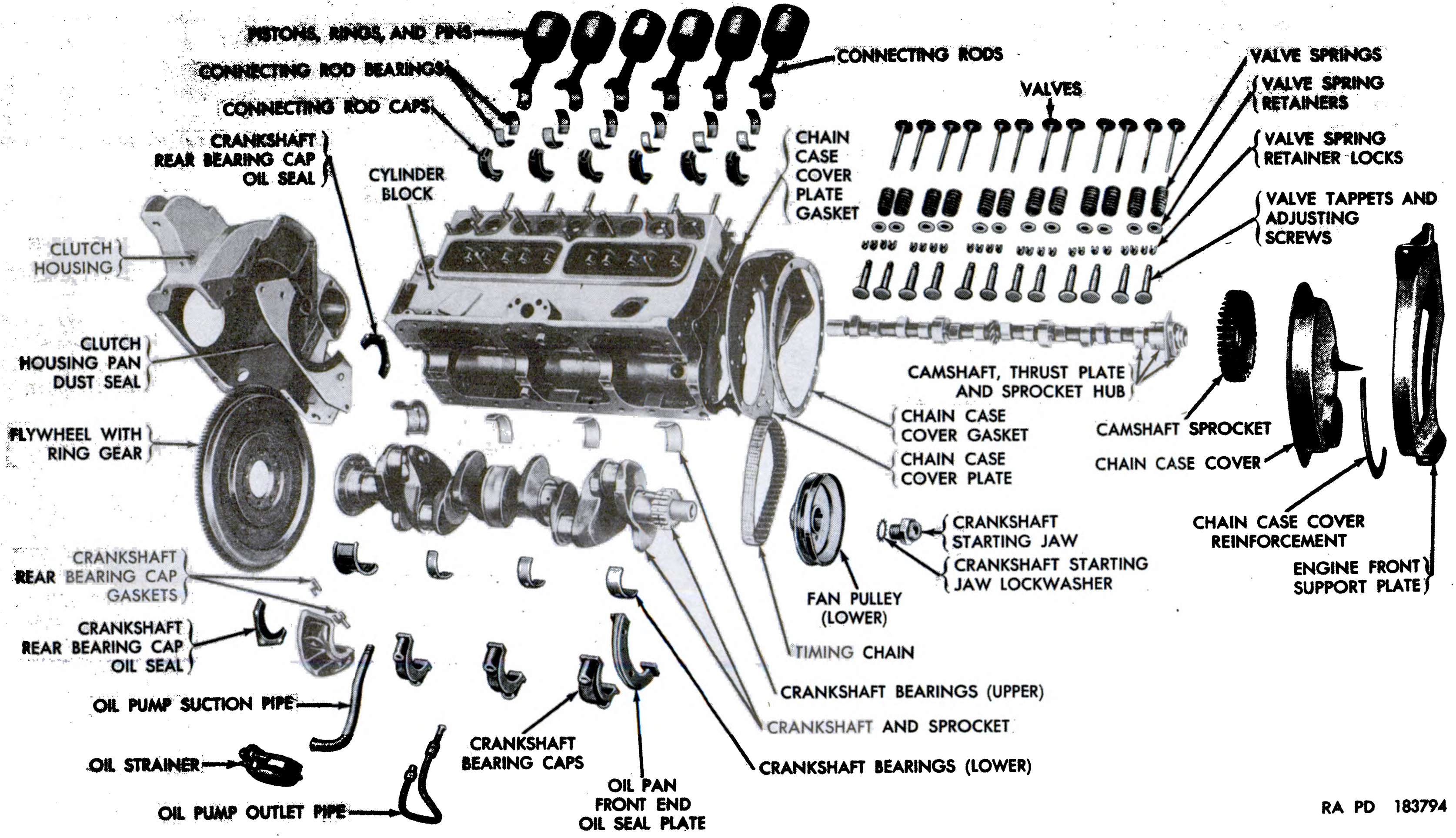

PISTONS, RINGS, AND PINS
CONNECTING ROD BEARINGS
CONNECTING ROD CAPS
CRANKSHAFT REAR BEARING CAP OIL SEAL
CYLINDER BLOCK
CLUTCH HOUSING
CLUTCH HOUSING PAN DUST SEAL
FLYWHEEL WITH RING GEAR
CRANKSHAFT REAR BEARING CAP GASKETS
CRANKSHAFT REAR BEARING CAP OIL SEAL
OIL PUMP SUCTION PIPE
OIL STRAINER
OIL PUMP OUTLET PIPE
CRANKSHAFT BEARING CAPS
OIL PAN FRONT END OIL SEAL PLATE
CONNECTING RODS
CHAIN CASE COVER PLATE GASKET
VALVES
VALVE SPRINGS
VALVE SPRING RETAINERS
VALVE SPRING RETAINER LOCKS
VALVE TAPPETS AND ADJUSTING SCREWS
CAMSHAFT, THRUST PLATE AND SPROCKET HUB
CHAIN CASE COVER GASKET
CHAIN CASE COVER PLATE
CAMSHAFT SPROCKET
CHAIN CASE COVER
CHAIN CASE COVER REINFORCEMENT
ENGINE FRONT SUPPORT PLATE
CRANKSHAFT STARTING JAW
CRANKSHAFT STARTING JAW LOCKWASHER
FAN PULLEY (LOWER)
TIMING CHAIN
CRANKSHAFT BEARINGS (UPPER)
CRANKSHAFT AND SPROCKET
CRANKSHAFT BEARINGS (LOWER)
RA PD 183794

Figure 24. Cylinder block and components of a 6-cylinder, L-head, in-line, liquid-cooled engine.

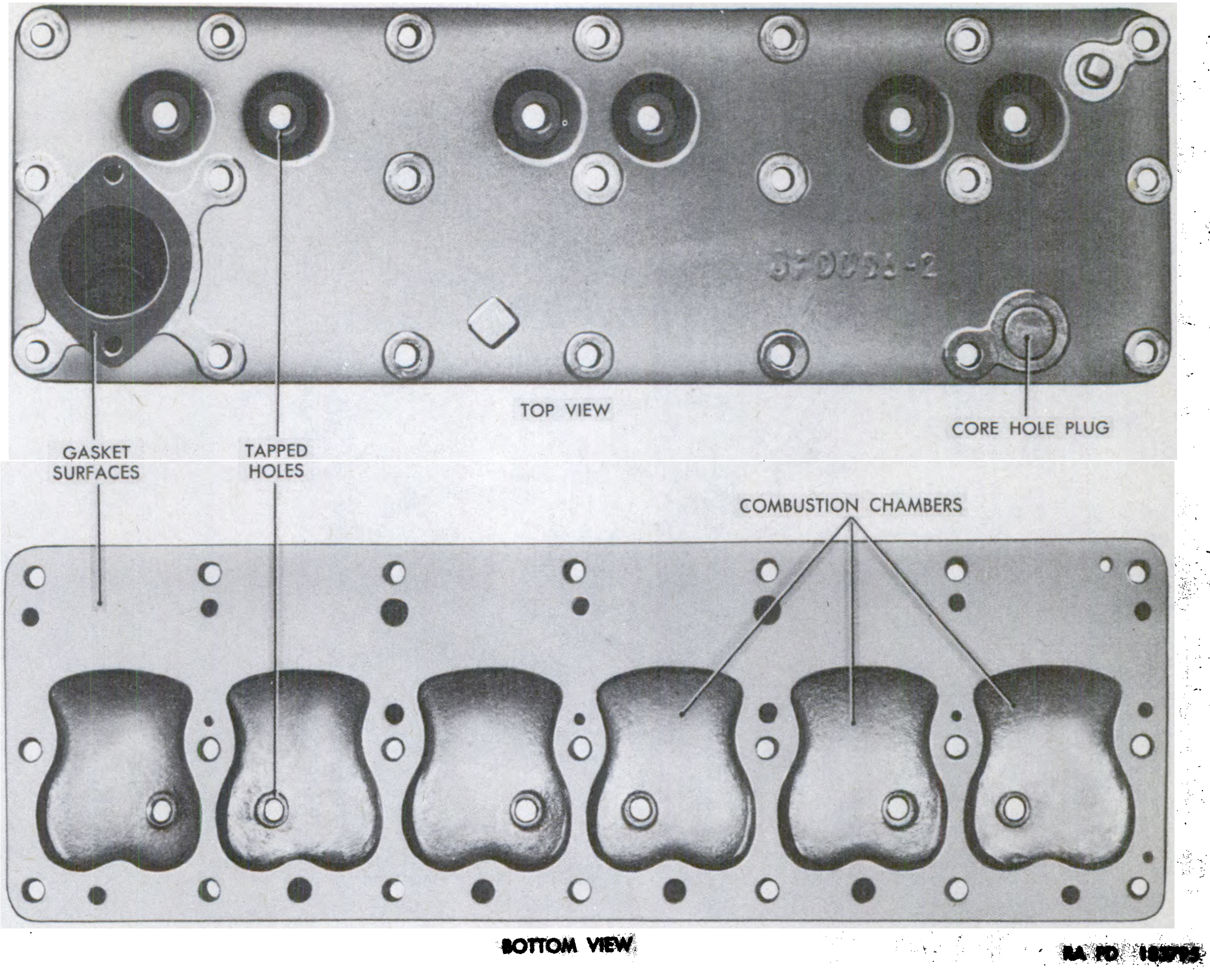


Figure 25. Cylinder head for a 6-cylinder, in-line L*-head, liquid-cooled engine.*

rocker arms, and rocker arm shaft. All cylinder heads were formerly made of cast iron, but many engines now are being built with cylinder heads of cast aluminum alloy because this material is a better conductor of heat, and there is less tendency for localized hot spots to develop. The aluminum alloy is light in weight and has a very favorable ratio of weight to strength at high temperatures.

19. Cylinder, Air-Cooled Engines

In air-cooled engines, the cylinders are separate and independently attached to the lower part of the engine (called the *crankcase*). The cylinder assembly is one of the most important parts of the air-cooled engine. The assembly consists of the barrel and the head. A 12-cylinder, V-type, air-cooled engine is shown in figure 26, while an exploded view of a cylinder from this engine is shown in figure 27. Figure 28 is an exploded view of a cylinder from a radial engine. The barrel of the air-cooled engine cylinder differs from that of a liquid-cooled engine in that it is made individually and is not cast enbloc (par. 17*b*). The cylinders are so located that air can flow all around them. In the V-type engine (fig. 26), two fans circulate air between and around the cylinders so that all cylinders are equally cooled. In the radial engine, the cylinders are equally spaced as radii in a circle and all are subjected equally to the air passing from front to back of the engine. The cylinders of air-cooled engines have closely spaced fins surrounding the barrel; these fins provide a greatly increased surface area from which heat can be dissipated. This is in contrast to the liquid-cooled engine, which has a water jacket around its cylinders.

a. The normal process of combustion generates high temperature and comparatively high pressure

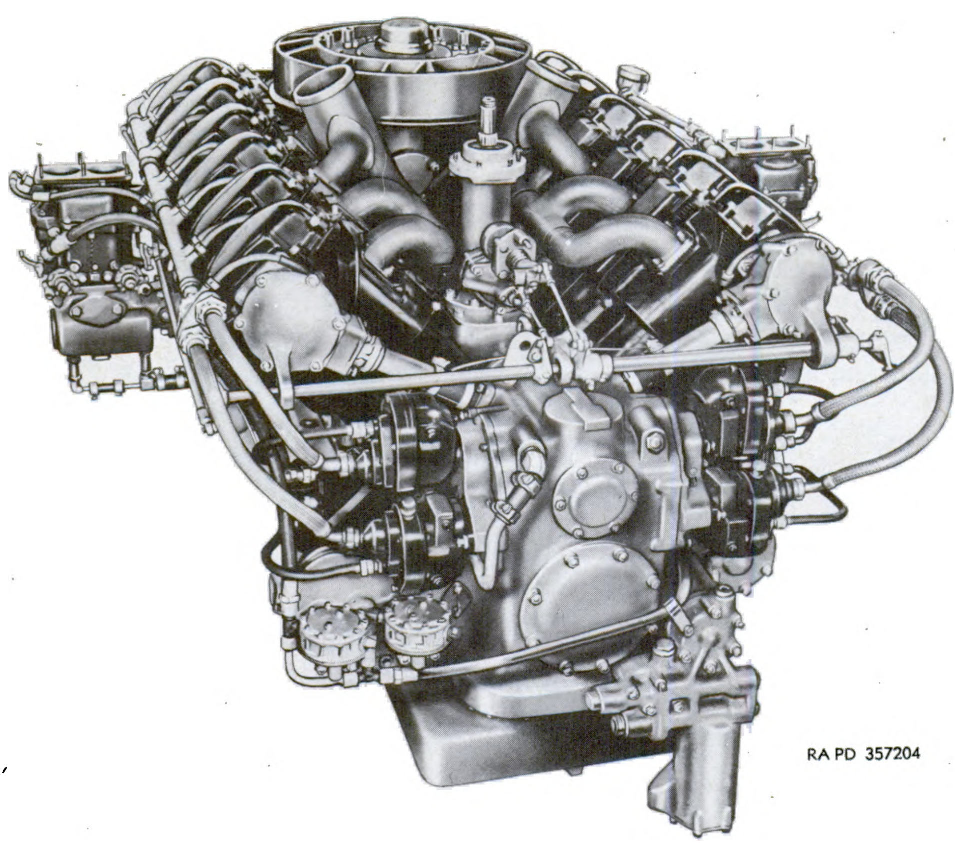


Figure 26. 12-cylinder, V-type, air-cooled engine—shrouds and front fan.

in the engine cylinder. If low-grade fuel is used or if the engine is operated at too high a temperature, detonation results (par. 49*c*) and the gas pressure caused by normal combustion is multiplied several times. This made it necessary for metallurgists to develop materials that retain their strength at high temperature and which are resistant to repeated stresses. Cylinder barrels are made of either cast nickel iron or forged steel. Because cast iron is heavy and comparatively weak under high temperatures, it is not used on large engines. However, it can be used on small engines where high strength and light weight are not important. Forged steel is far more satisfactory and is the prevalent material for cylinder barrels. The fins are machined on the outside of the barrel. The bearing surface on the inside is ground accurately and nitrided (toughened by exposure to an ammonia process under high temperature) to provide a hard, smooth, wear-resisting surface and reduce the possibility of distortion under high operating temperatures. A cylinder holddown flange is machined on the lower end of the barrel, where it is fastened to the main crankcase section by studs, nuts, and locking wire or locknuts.

b. Early air-cooled engines were manufactured with the cylinder barrel and the head cast integrally of nickel iron. The recent trend has been to make the head separately of an aluminum alloy. Aluminum is adaptable to the casting of deep, closely spaced fins; possesses a very favorable weight-strength ratio; and shows a tendency toward temperature equalization, thus eliminating hot spots. The aluminum-alloy head is screwed and shrunk on the barrel. The cylinder is not disassembled except by the manufacturer. In addition, some engines have an aluminum muff cast around the outside of each cylinder barrel. The muff is finned to aid in heat dissipation.

(1) The cooling fins of the cylinder assembly (figs. 27 and 28) run parallel to the air stream. The inner part of the head where the combustion chamber is located is dome-shaped and hemispherical. A hemispherical combustion chamber has a relatively small surface exposed to heat for

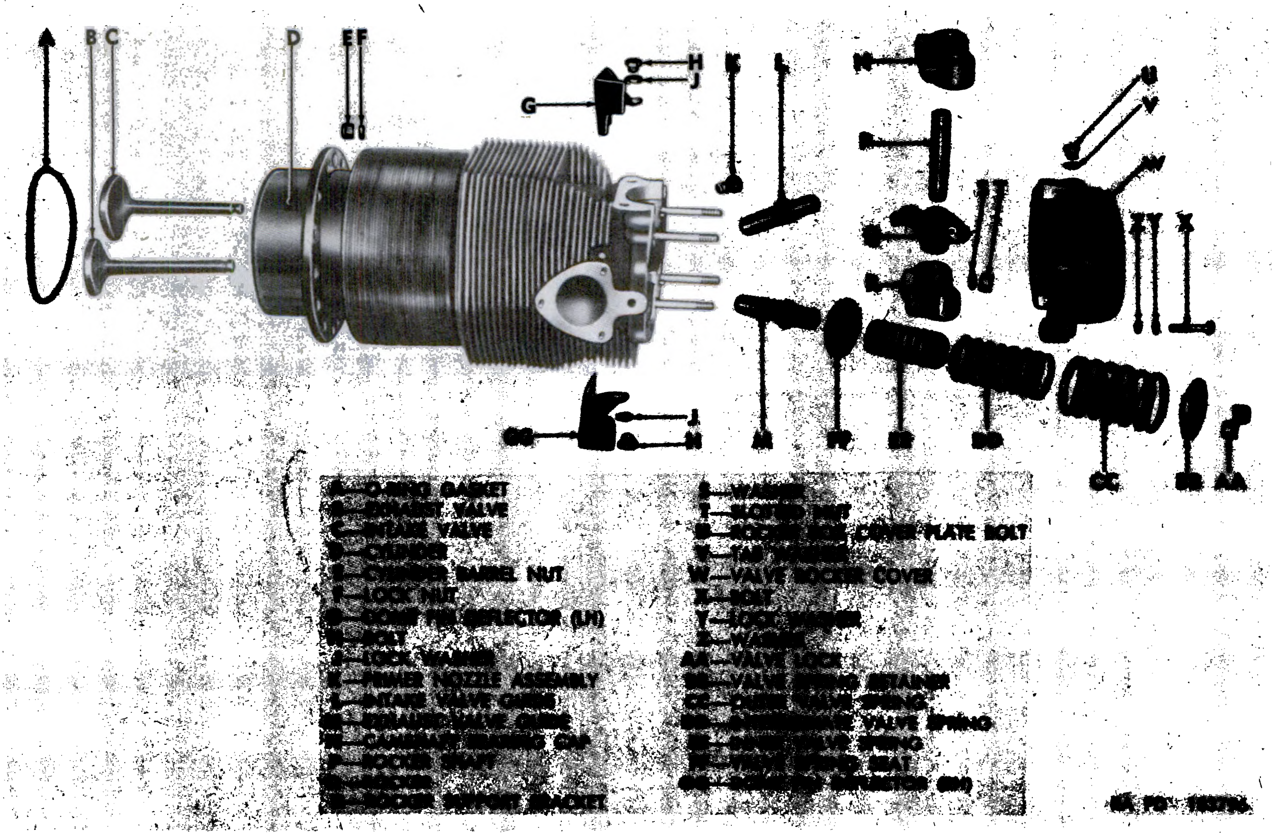

A—O-RING GASKET
B—EXHAUST VALVE
C—INTAKE VALVE
D—CYLINDER
E—CYLINDER BARREL NUT
F—LOCK NUT
G—DOWN FIN DEFLECTOR (LH)
H—BOLT
J—LOCK WASHER
K—PRIMER NOZZLE ASSEMBLY
L—INTAKE VALVE GUIDE
M—EXHAUST VALVE GUIDE
P—ROCKER SHAFT
R—ROCKER SUPPORT BRACKET
S—WASHER
T—SLOTTED NUT
U—ROCKER BOX COVER PLATE BOLT
V—TAB WASHER
W—VALVE ROCKER COVER
X—BOLT
Y—LOCK WASHER
Z—WASHER
AA—VALVE LOCK
BB—VALVE SPRING RETAINER
CC—OUTER VALVE SPRING
DD—INTERMEDIATE VALVE SPRING
EE—INNER VALVE SPRING
FF—VALVE SPRING SEAT
GG—DOWN FIN DEFLECTOR (RH)

Figure 27. Cylinder assembly of a 12-cylinder, V-type, air-cooled engine—exploded view.

a given volume of intake charge. This reduces total heat dissipation through the cylinder head and makes the cylinder more efficient. Two spark plugs also are located in the head to give uniform combustion.

(2) Intake valve seats and guides are usually made of aluminum-bronze alloy. On the exhaust side of the head, a high-temperature noncorrosive steel is used, which is tough enough to resist wear and the high temperatures of the exhaust gases. The guides are readily replaceable, but the seats usually are not replaced, except during rebuild.

(3) Since aluminum is a relatively soft material, it is necessary to reinforce the screw threads in the spark-plug holes in the head. Otherwise, these screw threads would soon wear out and the head would have to be discarded. A special spiral-shaped reinforcement, called an insert, is used for this purpose. The insert lines the aluminum screw threads with steel. Then, when the spark plug is screwed in and out, its threads work on the insert and not on the aluminum threads. The insert is made of specially shaped steel wire and is installed by threading it into place with special tools. In this application, the end of the insert has serrated staking teeth which permits staking into place so it will not loosen. The insert can be replaced with special tools if it becomes worn or damaged.

20. Crankcase, Liquid-Cooled Engines

a. The crankcase is that part of the engine which supports and incloses the crankshaft, provides a reservoir for the lubricating oil, and acts as a support for the oil pump, oil filter, and some of the other accessories. It is common practice to cast the upper part of the crankcase as part of the cylinder block. The lower part of the crankcase is the oil pan (AA, fig. 29), which is bolted to the bottom of the block. It is made of pressed or cast metal.

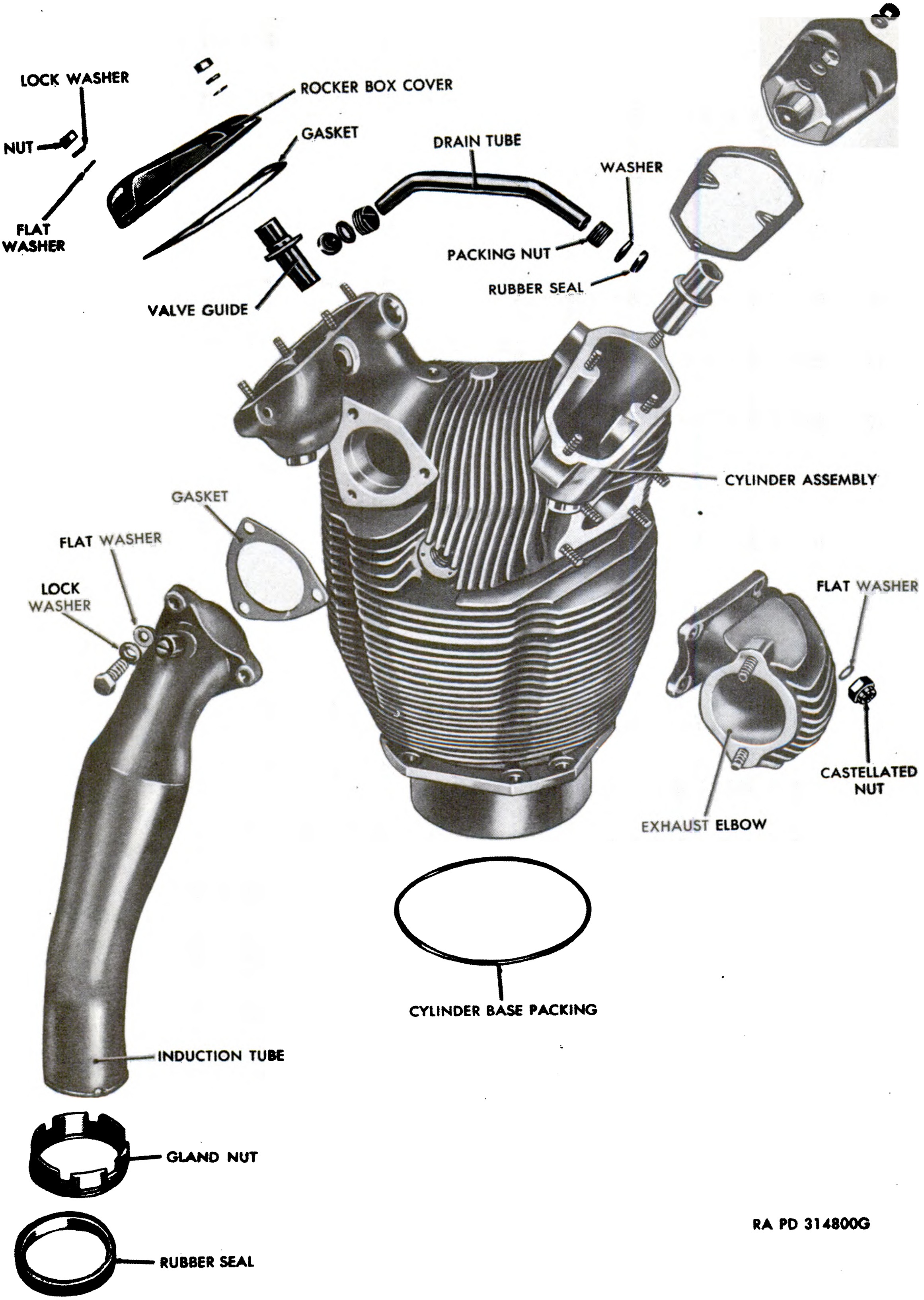
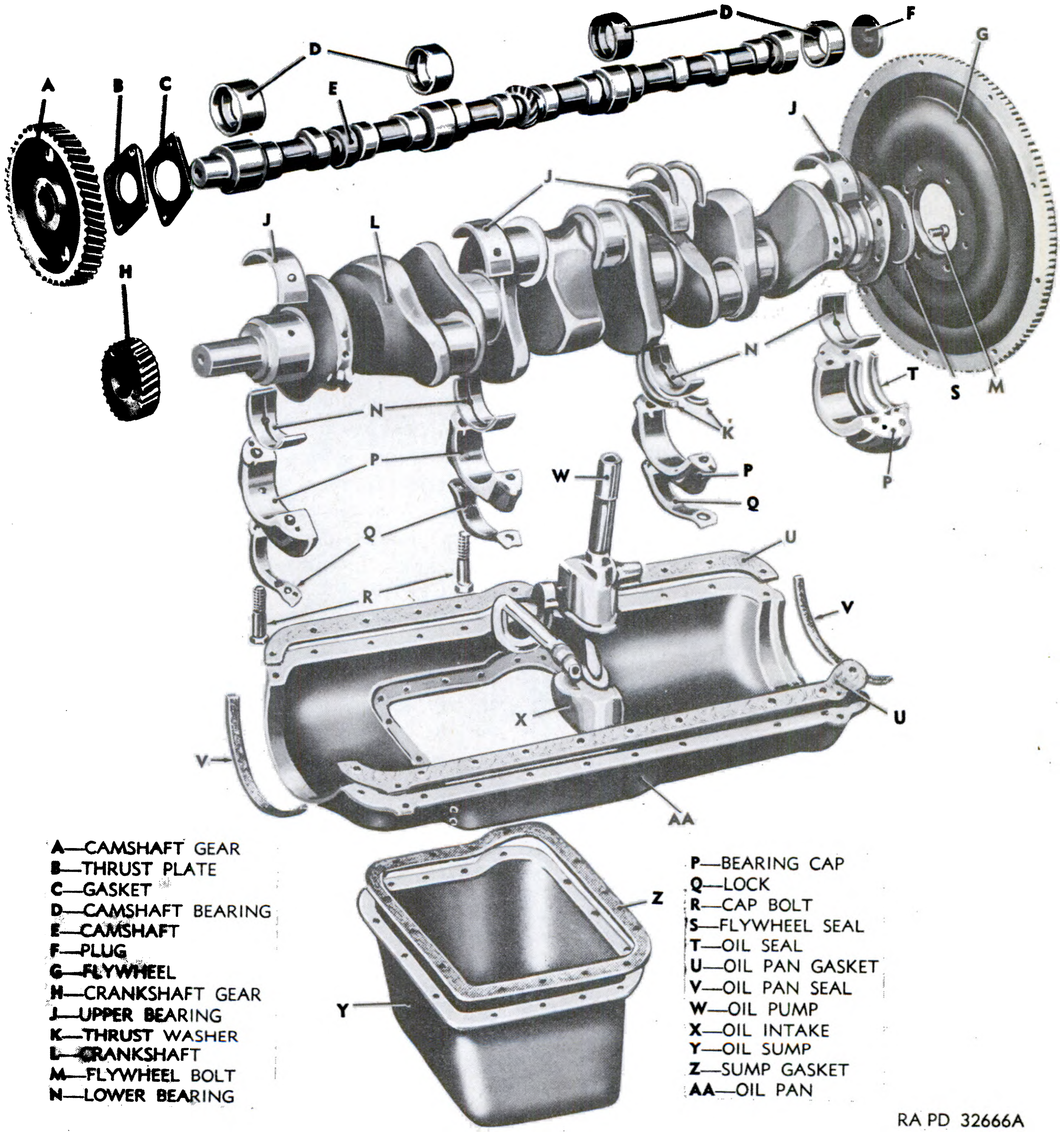

LOCK WASHER
NUT
FLAT WASHER
ROCKER BOX COVER
GASKET
DRAIN TUBE
WASHER
PACKING NUT
RUBBER SEAL
VALVE GUIDE
CYLINDER ASSEMBLY
GASKET
FLAT WASHER
LOCK WASHER
FLAT WASHER
CASTELLATED NUT
EXHAUST ELBOW
CYLINDER BASE PACKING
INDUCTION TUBE
GLAND NUT
RUBBER SEAL
RA PD 314800G

Figure 28. Cylinder assembly of a radial engine—exploded view.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R
V
U
X
V
AA
Z
Y
A—CAMSHAFT GEAR
B—THRUST PLATE
C—GASKET
D—CAMSHAFT BEARING
E—CAMSHAFT
F—PLUG
G—FLYWHEEL
H—CRANKSHAFT GEAR
J—UPPER BEARING
K—THRUST WASHER
L—CRANKSHAFT
M—FLYWHEEL BOLT
N—LOWER BEARING
P—BEARING CAP
Q—LOCK
R—CAP BOLT
S—FLYWHEEL SEAL
T—OIL SEAL
U—OIL PAN GASKET
V—OIL PAN SEAL
W—OIL PUMP
X—OIL INTAKE
Y—OIL SUMP
Z—SUMP GASKET
AA—OIL PAN
RA PD 32666A

Figure 29. Oil pan and lower engine parts.

b. The crankcase also has the mounting brackets which support the entire engine on the vehicle frame, or on a subframe designed and constructed for that purpose. The engine mounting supports are an integral part of the crankcase or are bolted to it in such a way that they support the engine at three or four points. The points of contact with the frame are usually cushioned on rubber. The rubber mechanically insulates the frame and body of the vehicle from engine vibration and noise, and prevents frame distortion and damage to the engine supports and transmission from engine twisting.

21. Crankcase, Air-Cooled Opposed- and V-Type Engines

In the air-cooled horizontal-opposed or V-type engines, the crankcase is the foundation of the engine since the individual cylinders are attached to it, the crankshaft is inclosed by it, and the oil pan and other parts are fastened to it. Figure 30 shows the crankcase and related parts of a 12-cylinder, air-cooled, V-type engine. The studs to which one bank of individual cylinders are attached can be seen along the upper left of the crankcase (D, fig. 30). To permit higher stresses in the studs set in the aluminum casting, special Rosan inserts are installed so that the studs can be threaded into them. These inserts are screwed into the softer casting until they are slightly below the surface. When an insert is set, a lock ring, broached to fit the splined end of the insert and course-milled on its outer edge, is driven into a counterbore in the casting. This lock ring holds the threaded insert in place and prevents any turning of the insert when a stud is installed or removed.

22. Crankcase, Radial Engine

The radial engine crankcase (fig. 31) is composed of several aluminum-alloy castings fastened together with studs through flanges. The crankcase forms the foundation on which the entire engine is assembled and is made up of the front crankcase section, the front main bearing support section, the main crankcase section, the diffuser section, and the accessory, or rear, crankcase section.

a. Front Crankcase Section. The front crankcase section is the part which is nearest the propeller in an airplane and nearest the flywheel in an automotive vehicle. Its design and construction are considered important in airplane use because of the varied forces and vibrations caused by the propeller; but in automotive use, the principal concerns are that it is oiltight and that it gives rapid, uniform heat conduction. It houses the ball thrust bearing (par. 30*c*) and the crankshaft-driven front scavenger pump which picks up oil from the front of the sump and directs it into the oil reservoir.

b. Front Main Bearing Support Section. The front main bearing support section is a diaphragm of cast aluminum alloy, which supports the front main roller bearing.

c. Main Crankcase Section. Construction of the main crankcase section is particularly important as it holds the cylinders and is subjected to considerable stress, especially if the engine is detonating. On the main crankcase section are the cylinder pads, machined surfaces upon which the cylinder flanges are mounted.

d. Diffuser Section. The rear side of the diffuser section forms the front wall of the diffuser, which deflects the air stream from the impeller to the cylinders (par. 58*a*). The impeller is also mounted on the diffuser section. It supports the impeller drive and two accessory-drive idler gears. Three bushings in the diffuser section support the forward ends of the starter shaft and two accessory drive shafts. These shafts extend through the diffuser chamber to the accessory crankcase section.

e. Accessory Crankcase Section. The accessory, or rear, crankcase section supports the accessory drives and provides pads for mounting the various accessories: magnetos, carburetor, starter, generator, fuel pump, tachometer drive, and oil pump. The forward end of the section forms the rear wall of the diffuser and provides the intake pipe connections (par. 55).

23. Pistons

a. Fitted into the bore of the cylinder is a movable piston that receives the energy or force of combustion and transmits that energy to the crankshaft through the connecting rod (fig. 32). Automotive pistons ordinarily are made of cast iron or aluminum alloy. They must be light, wear well, and have high strength. At the top and bottom of the strokes of the cycle, the piston must come to a complete stop and start again in the opposite direction. Considerable force is required to overcome the inertia of the piston when it stops and starts and, as the weight of the piston affects the inertia, it is desirable to keep the piston as light as possible. To reduce weight, the head and skirt of the piston are made as thin as is consistent with the strength required. Ribs are used on the underside of the piston to reinforce the head; they also assist in conducting heat from the head of the piston to the piston rings and out through the cylinder walls. Special ribs are used to reinforce the piston pin bosses. The radial engine piston varies only slightly in construction from the one used in the in-line or V-type engines. These variations exist only because the radial engine piston must have greater cooling capacity and less weight and yet retain its strength. Because of this, aluminum alloy is the favored material for radial engine pistons. Besides its rapid heat-conducting and strength characteristics, aluminum is adaptable to several manufacturing processes as it is readily machinable. The forged piston is preferable for radial engine pistons as it is made of denser metal, which is less subject to warpage and is able to withstand considerable stress and strain.

b. The piston is kept in alinement by the skirt, which is usually cam ground and elliptical in cross section (fig. 33). This elliptical shape permits the piston to fit the cylinder, regardless of whether the piston is cold or at working temperature. Its narrowest diameter is at the piston pin bosses, where the metal is thickest. At its widest diameter, the piston skirt is thinnest. The piston is fitted to close limits at its widest diameter so that piston "slaps" will be prevented during engine warm-up. As the piston is expanded by the heat generated during operation, it becomes round, because the expansion is proportional to the temperature of the metal. The walls of the skirt are cut away as much as possible to reduce weight and to prevent excessive expansion during engine operation. Many aluminum pistons are made with split skirts so that when the pistons expand, the skirt diameter will not increase. The two types of piston skirts found in engines are the full trunk and the slipper. The full-trunk-type skirt, which is more widely used, has a full cylindrical shape with bearing surfaces parallel to those of the cylinder, giving more strength and better control of the oil film. The slipper-type skirt has considerable relief on the sides of the skirt, leaving less area for possible contact with the cylinder walls and thereby reducing friction.

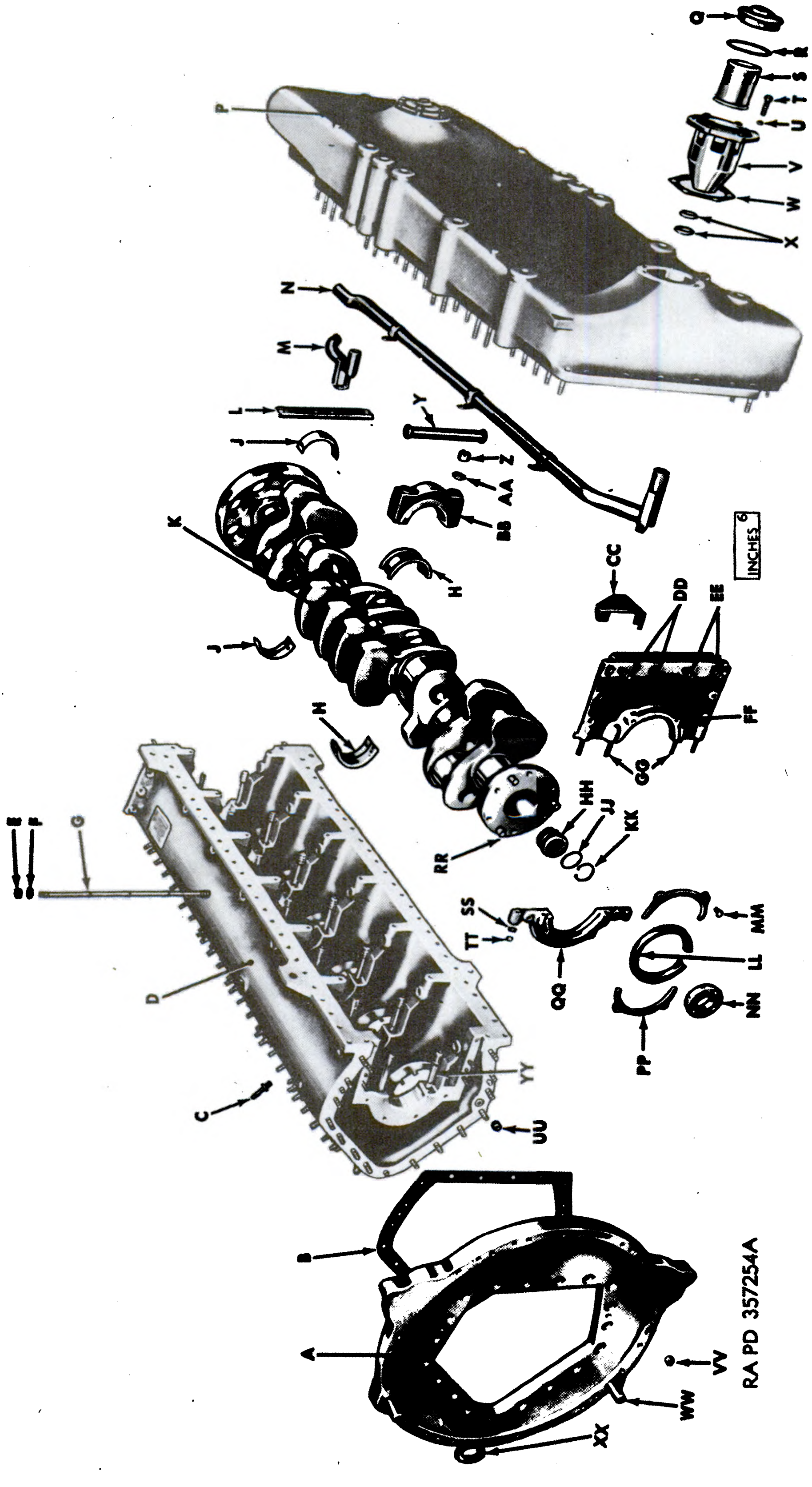
c. It is common practice today for some manufacturers to use pistons that have been plated with a soft material like tin. The purpose is to have the tin work into and fill the pores of the cylinder wall as the engine is broken in. The result is a more perfect fit between the piston and cylinder wall and a shorter breaking-in period. Aluminum pistons are often "anodized" to make the outside surface harder. Anodizing is a process whereby the piston is oxidized by electrolysis. It produces an aluminum-oxide coating over the entire surface of the piston. This coating is very hard and highly resistant to wear. Because of the softness of aluminum, pistons made of this material, unless properly treated, may pick up gritty particles which will become embedded in the piston, causing scratches and wear in the cylinder walls.

24. Piston Rings

Piston rings are used on pistons to maintain gas-tight seals between the pistons and cylinders, to assist in cooling the piston, and to control cylinder-wall lubrication. About one-third of the heat absorbed by the piston passes through the rings to the cylinder wall. Although piston rings have been made from many materials, cast iron has proved the most satisfactory, as it withstands heat, forms a good wearing surface, and retains a greater amount of its original elasticity after considerable use. More recently, piston rings are being plated with various metals to produce better wearing qualities. There are two types of piston rings: compression rings and oil-regulating rings. These are shown in figure 34.

a. Compression Ring. The principal function of a compression ring is to prevent gases from leaking by the piston during the compression and power strokes. All piston rings are split to permit easy assembly to the piston and to allow for expansion. When the ring is in place, the ends of the split joint do not form a perfect seal; therefore, it is common practice to use more than one ring and to stagger the joints around the piston. If cylinders are worn, expanders are sometimes used to insure a perfect seal.

b. Oil Regulating Ring. The lowest ring above the piston pin is usually an oil regulating ring. This ring scrapes the excess oil from the cylinder walls and returns some of it, through slots, to the piston ring grooves. The ring groove under an oil ring is provided with openings through which the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INCHES 6

RA PD 357254A

A	Transmission case adapter
B	Adapter gasket
C	Rocker box oil drain line adapter
D	Crankcase
E	Special nut
F	Plain washer
G	Crankcase cross bolt
H	Crankshaft thrust bearing
J	Crankshaft main bearing
K	Crankshaft
L	Pressure oil line support bracket
M	Pressure oil pump inlet line assy
N	Scavenger oil pump inlet line assy
P	Oil pan
Q	Oil sump screen plug
R	Annular gasket
S	Oil sump screen assy
T	Drilled-head bolt
U	Plain washer
V	Oil sump screen housing
W	Screen housing gasket
X	O-ring gasket
Y	Crankcase cross bolt spacer
Z	Main bearing cap nut
AA	Main bearing cap washer
BB	Main bearing cap
CC	Scavenger oil line support bracket
DD	Transmission adapter stud
EE	Drilled stud
FF	Crankshaft oil seal housing (lower)
GG	Drilled stud
HH	Crankshaft flywheel end plug
JJ	O-ring gasket
KK	Snap ring
LL	Oil seal
MM	Drilled-head bolt
NN	Transmission shaft pilot ball bearing
PP	Oil seal retaining plate
QQ	Crankshaft oil seal housing (upper)
RR	Dowel pin
SS	Plain washer
TT	Slotted nut
UU	Pipe plug
VV	Slotted nut
WW	Dowel pin

Figure 30. Crankcase and related parts of a 12-cylinder air-cooled, V-type engine.

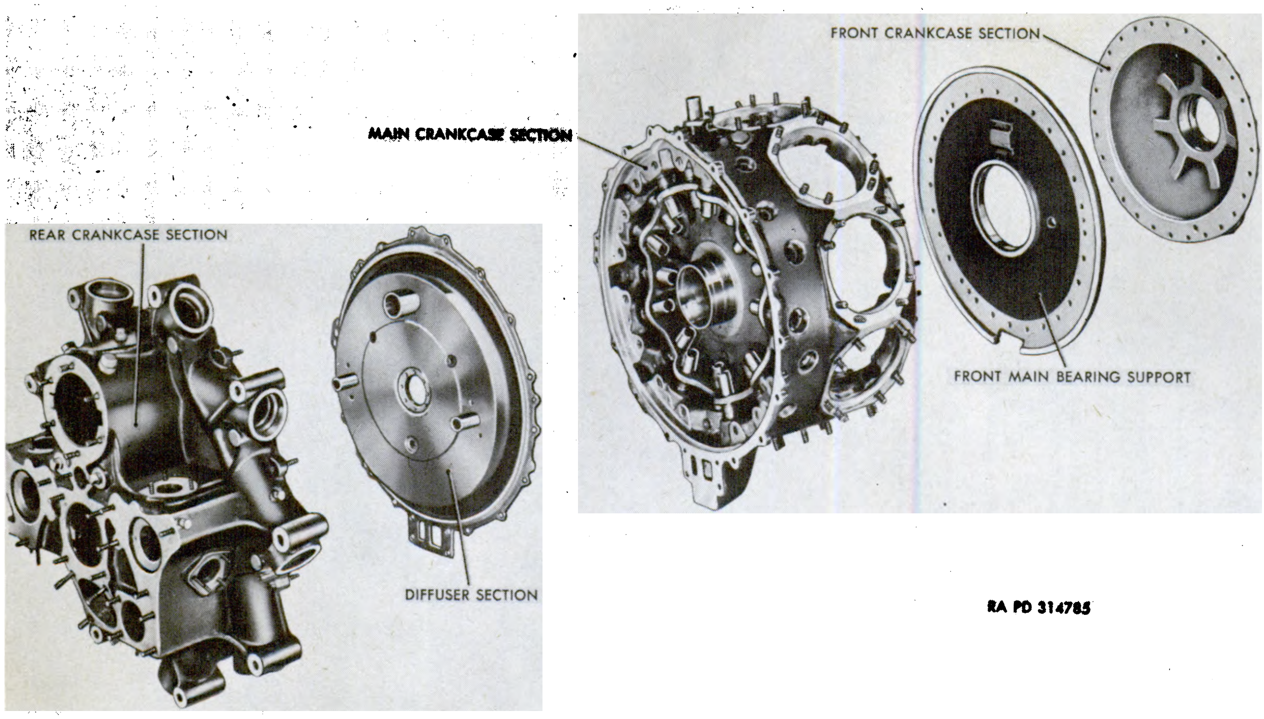

FRONT CRANKCASE SECTION
MAIN CRANKCASE SECTION
REAR CRANKCASE SECTION
FRONT MAIN BEARING SUPPORT
DIFFUSER SECTION
RA PD 314785

Figure 31. Radial engine crankcase components.

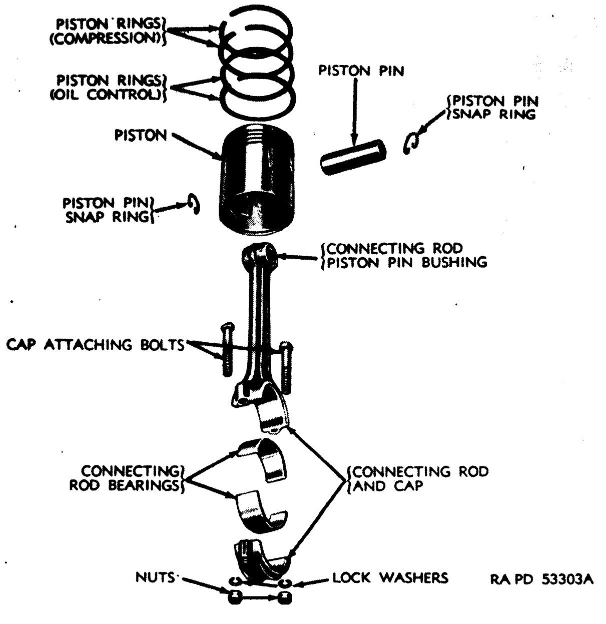

PISTON RINGS (COMPRESSION)
PISTON RINGS (OIL CONTROL)
PISTON PIN
PISTON PIN SNAP RING
PISTON
PISTON PIN SNAP RING
CONNECTING ROD PISTON PIN BUSHING
CAP ATTACHING BOLTS
CONNECTING ROD BEARINGS
CONNECTING ROD AND CAP
NUTS
LOCK WASHERS
RA PD 53303A

Figure 32. Piston, piston rings, connecting rod, and connecting rod bearings.

oil flows back into the crankcase. In some engines, an additional oil ring is used in the skirt below the piston pin, thus providing better control of the oil. Steel side plates are sometimes used on 2- and 3-section oil regulating rings.

25. Piston Pins

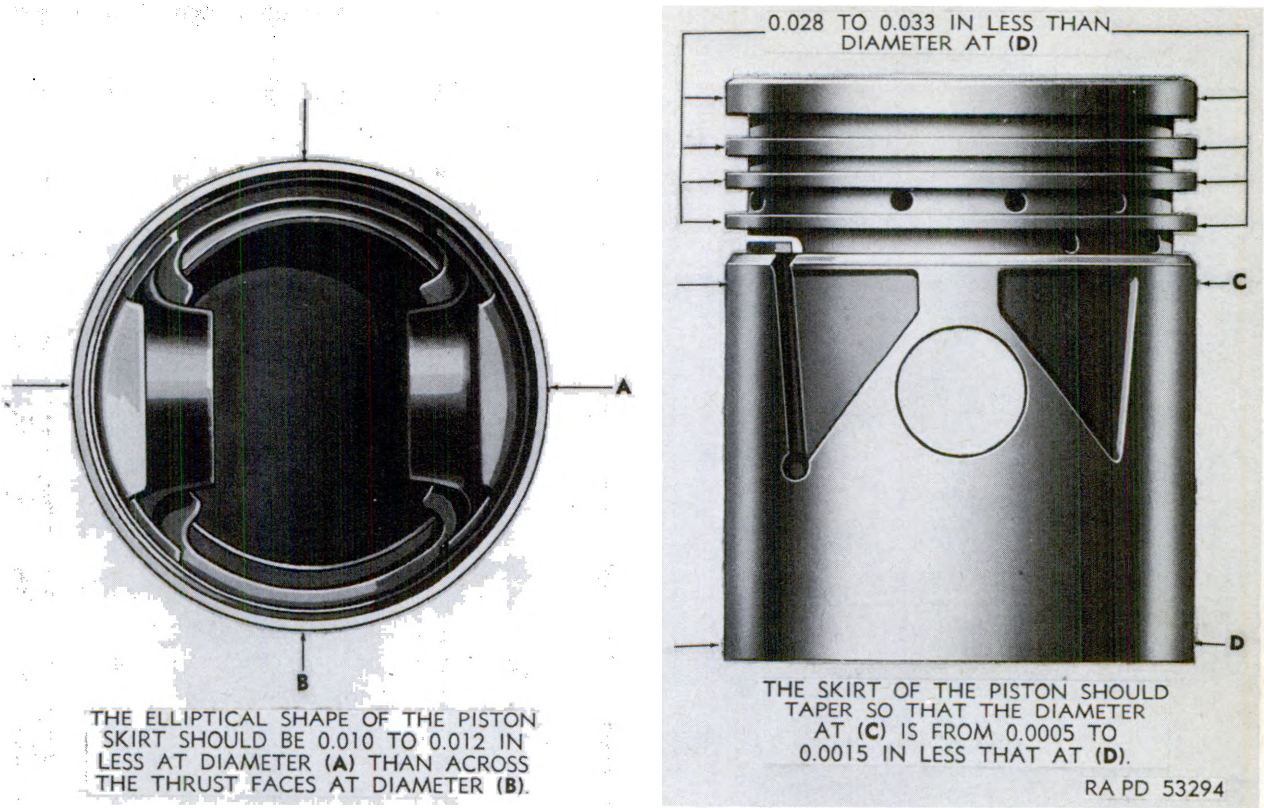
a. The piston is attached to the connecting rod by means of the piston pin. The pin passes through the piston pin bosses and through the upper end of the connecting rod, which rides within the piston on the middle of the pin. Piston pins are made of alloy steel with a precision finish and are case-hardened and sometimes chromium-plated to increase their wearing qualities. Their tubular construction gives them a maximum of strength with a minimum of weight. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rods.

b. There are three methods of fastening a piston pin (fig. 35) to the piston and connecting rod.

(1) An anchored, or "fixed," pin is attached to the piston by a screw running through one of the bosses; the connecting rod oscillates on the pin.

(2) A "semifloating" pin is anchored to the connecting rod and turns in the piston pin bosses.

(3) A "full-floating" pin is free to rotate in the connecting rod and in the bosses, but is prevented from working out against the sides of the cylinder by plugs or snap-ring locks.



THE ELLIPTICAL SHAPE OF THE PISTON SKIRT SHOULD BE 0.010 TO 0.012 IN LESS AT DIAMETER **(A)** THAN ACROSS THE THRUST FACES AT DIAMETER **(B)**.

0.028 TO 0.033 IN LESS THAN DIAMETER AT **(D)**

THE SKIRT OF THE PISTON SHOULD TAPER SO THAT THE DIAMETER AT **(C)** IS FROM 0.0005 TO 0.0015 IN LESS THAT AT **(D)**.

Figure 33. Cam-ground piston.

26. Connecting Rods

a. The connecting rods (fig. 32) connect the pistons with the crankshaft. They must be light and yet strong enough to transmit the thrust of the pistons. Automotive connecting rods are drop-forged from a steel alloy capable of withstanding heavy loads without deflection, that is, without bending or twisting. The connecting rod generally is made in the form of an I-beam for lightness with maximum strength. Holes at the upper and lower ends are machined to permit accurate fitting of bearings. These holes must be parallel.

b. The upper end of the connecting rod is connected to the piston by the piston pin. If the piston pin is locked in the piston pin bosses or if it floats in both piston and connecting rod, the upper hole of the connecting rod will have a solid bearing (more commonly called a bushing) of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to turn back and forth on the piston pin. Although this movement is not great, the bushing is necessary because the temperatures and unit pressures exerted are high. If the piston pin is semifloating (par. 25*b*(2)), a bushing is not needed.

c. The lower hole of the connecting rod is split to permit it to be clamped around the crankshaft. The bottom part, or cap, is made of the same material as the rod and is attached by two or more connecting rod bolts. The surface that bears on the crankshaft is generally a bearing material in the form of a separate split shell, although in a few cases, it may be spun or die-cast in the inside of the rod and cap during manufacture. The two parts of the separate bearing are positioned in the rod and cap by dowel pins, projections, or short brass screws. The shell may be of babbitt metal face-spun or die-cast on a backing of bronze or steel. Split bearings may be of the precision or semiprecision type.

(1) The precision type is accurately finished to fit the crankpin and does not require further machining during installation. It is positioned by projections on the shell which match reliefs in the rod and cap. The projections prevent the bearings from moving sideways, but they permit rotary movement after the bearing cap

is removed, thus, making is possible to replace the bearing without removing the connecting rod from the engine.

(2) The semiprecision type is usually fastened to the rod and cap. Prior to installation, it is machined to the proper inside diameter with the cap and rod bolted together.

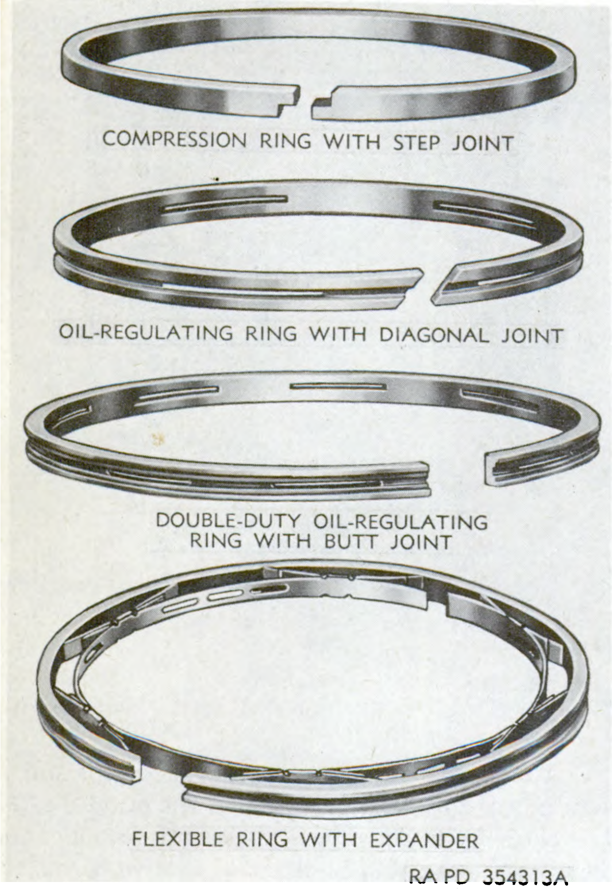

COMPRESSION RING WITH STEP JOINT
OIL-REGULATING RING WITH DIAGONAL JOINT
DOUBLE-DUTY OIL-REGULATING RING WITH BUTT JOINT
FLEXIBLE RING WITH EXPANDER
RA PD 354313A

Figure 34. Piston rings.

27. Crankshaft

a. Function. The crankshaft might well be called the backbone of the engine, as it ties together the reaction of all the pistons, transforms the reciprocating motion of the pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel and clutch. The crankshaft (fig. 36) is a shaft with one or more throws along its length. The arrangement of the throws along the crankshaft is determined by the desired firing order of the engine cylinders. The desired firing order is regulated by the relationship of the camshaft and the crankshaft.

b. Construction. Crankshafts are first forged or cast from an alloy of steel and nickel. The rough casting or forging is then machined. When all the rough machining is completed, the nonbearing surfaces are plated with a light coating of copper. When the plating process is completed, the whole crankshaft is placed in a carburizing oven or an electroinduction furnace, where surfaces of the crankshaft not coated with copper become alloyed with the carbon, producing a thin, hard surface or bearing area. This process is known as *case-hardening*. The crankshaft is completed by grinding the case-hardened surfaces.

c. Throw Arrangement (fig. 37). Crankshafts for 4-cylinder engines have either three or five points of support (i. e. supporting bearings). The four throws are in one plane, the throws for cylin-

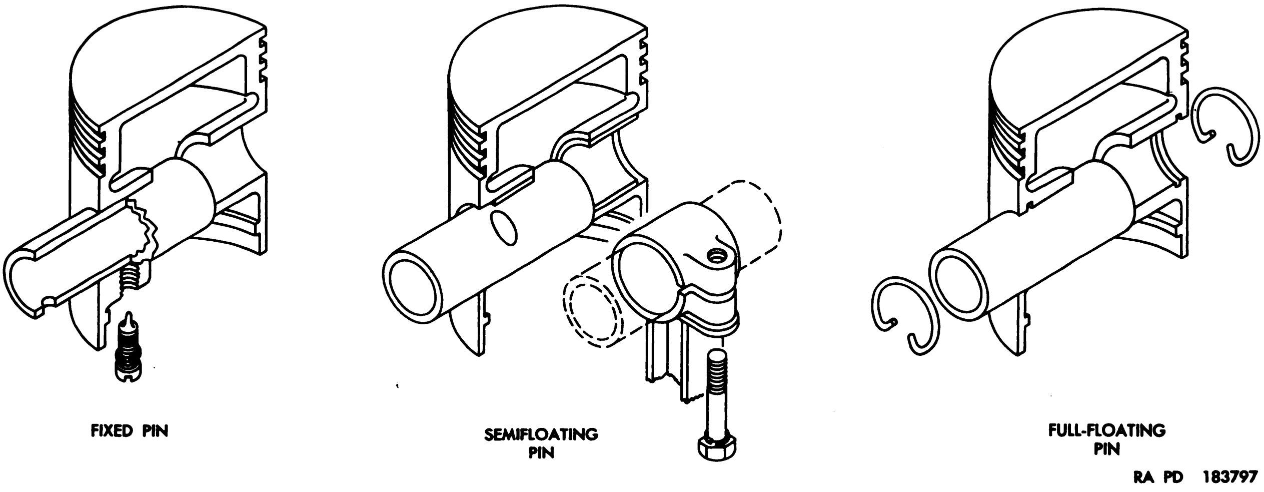
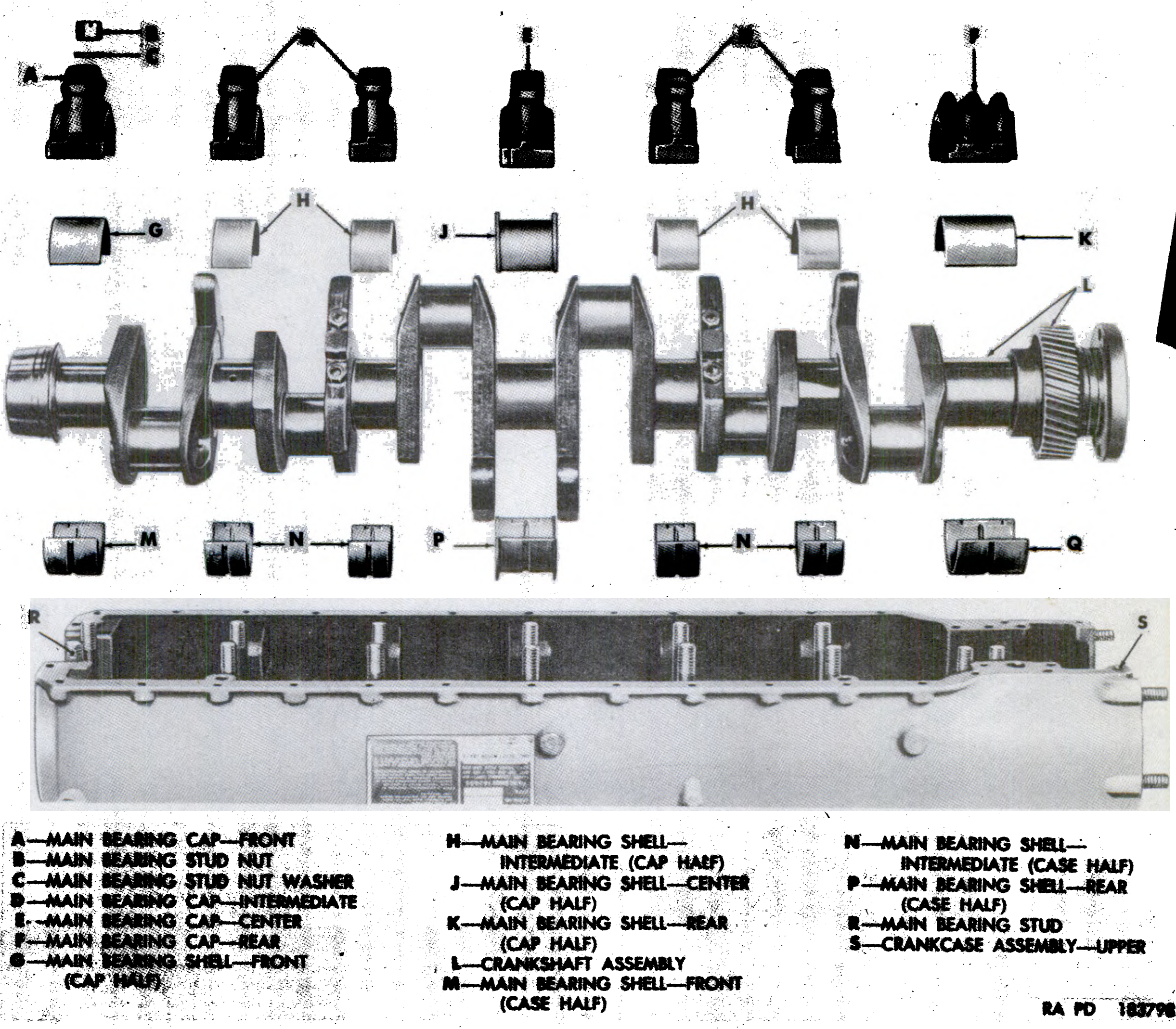

FIXED PIN
SEMIFLOATING PIN
FULL-FLOATING PIN
RA PD 183797

Figure 35. Piston pin arrangements.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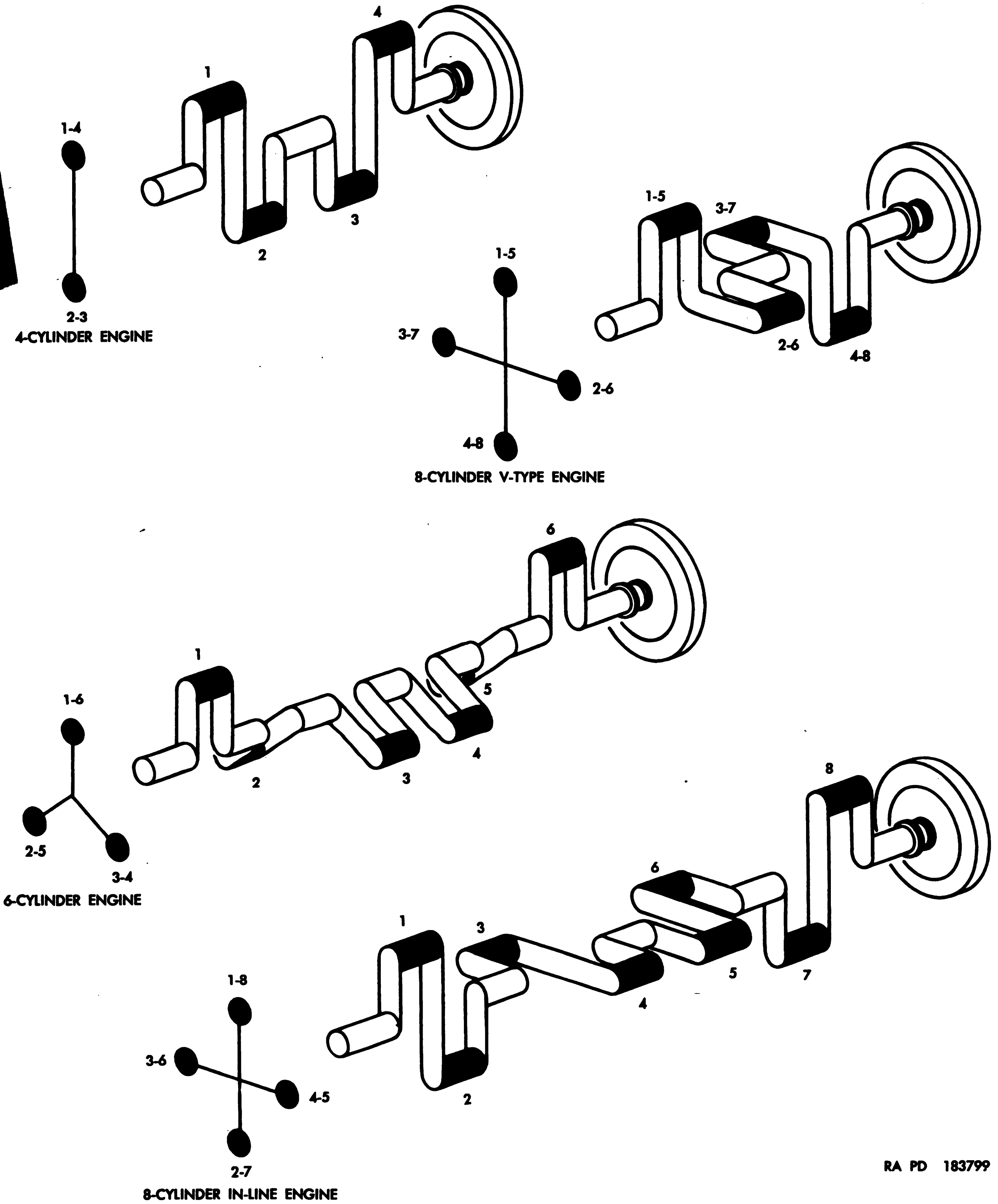
R
S
A—MAIN BEARING CAP—FRONT
B—MAIN BEARING STUD NUT
C—MAIN BEARING STUD NUT WASHER
D—MAIN BEARING CAP—INTERMEDIATE
E—MAIN BEARING CAP—CENTER
F—MAIN BEARING CAP—REAR
G—MAIN BEARING SHELL—FRONT (CAP HALF)
H—MAIN BEARING SHELL—INTERMEDIATE (CAP HALF)
J—MAIN BEARING SHELL—CENTER (CAP HALF)
K—MAIN BEARING SHELL—REAR (CAP HALF)
L—CRANKSHAFT ASSEMBLY
M—MAIN BEARING SHELL—FRONT (CASE HALF)
N—MAIN BEARING SHELL—INTERMEDIATE (CASE HALF)
P—MAIN BEARING SHELL—REAR (CASE HALF)
R—MAIN BEARING STUD
S—CRANKCASE ASSEMBLY—UPPER
RA PD 183798

Figure 36. Crankshaft and bearings.

ders No. 2 and 3 being advanced 180° over the throws for cylinders No. 1 and 4. A crankshaft for an 8-cylinder **V**-type engine could be of the same basic design with two connecting rods being connected to each throw. For better balance and smoother operation, a variation of the **V**-type 8-cylinder crankshaft has two throws on each bank advanced 90° over the other two throws. Crankshafts for 8-cylinder in-line engines follow two general designs. The first design has two identical 4-throw arrangements positioned end to end, with one set advanced 90° over the other. This is known as a 4–4 shaft. In the other design, the 2–4–2 shaft, a set of four throws is positioned between two sets of two throws each. The end cylinders are advanced 90° over the center group. Crankshafts for 6-cylinder engines have either three, four, or seven points of support. The throws for the connecting rod bearings are forged in three planes 120° apart, with two throws in each plane. Throws No. 1 and 6 are in the first plane, No. 2 and 5 are in the second, and No. 3 and 4 are in the third. The crankshafts for 12-cylinder **V**-type engines are basically the same as the shafts for 6-cylinder engines.

d. Crankshaft Stress. Any piece of rotating machinery has a certain definite speed at which it will start to vibrate excessively; this is called the *critical speed.* In designing a crankshaft, it is sometimes possible to place this critical speed outside the speed range of the engine. If not, the crankshaft must be heavy enough to withstand the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4-CYLINDER ENGINE
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2-6
4-8
4-8
8-CYLINDER V-TYPE ENGINE
6
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1-6
5
4
2
3
2-5
3-4
6-CYLINDER ENGINE
8
6
1
3
1-8
5
7
4
3-6
4-5
2
2-7
8-CYLINDER IN-LINE ENGINE

RA PD 183799

Figure 37. Crankshafts and throw arrangements.

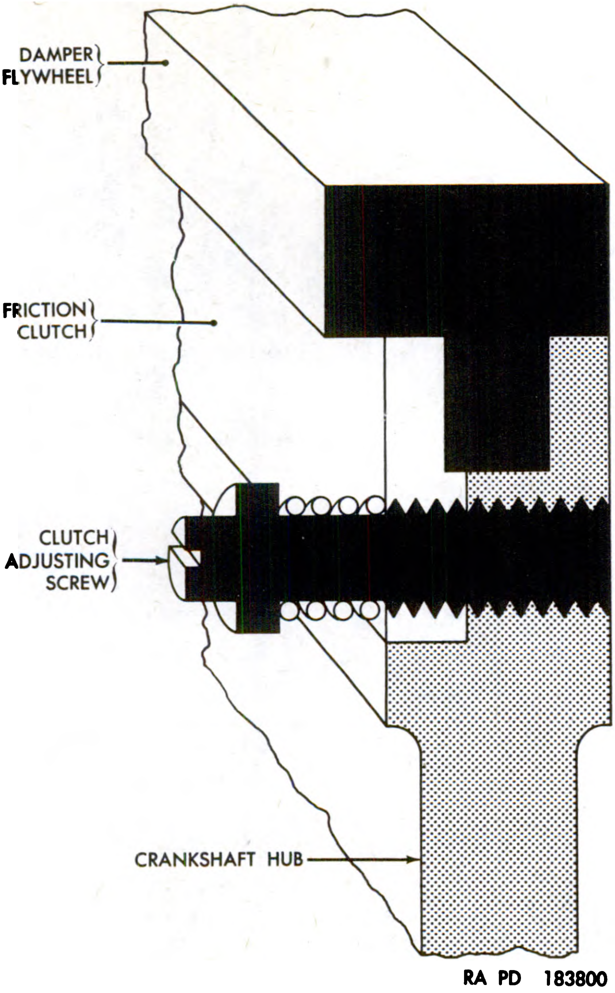


Figure 38. One type of vibration damper.

vibration. In severe cases of vibration, the crankshaft may break. To run smoothly, a crankshaft must be statically and dynamically balanced. Crankshaft deflection caused by load stresses will often throw a shaft out of balance, especially at high speeds. To overcome vibration, uneven balance, and load deflection, crankshafts are balanced by use of weights. These weights may be forged as part of the shaft, as shown in figure 36, or they may be bolted on.

e. Torsional Vibration. Torsional vibration is a twisting vibration. It usually is noticeable in in-line 6- and 8-cylinder engines with long crankshafts. Assume that the crankshaft is made of rubber. When the front cylinder is fired, it would tend to turn the crankshaft very rapidly, but the inertia of the flywheel would tend to prevent this rapid increase in speed at the rear of the crankshaft. The result is a "winding up" of the "rubber" crankshaft. As the force exerted by the front cylinder decreases, the rubber crankshaft will "unwind." This repeated winding and unwinding sets up a twisting or torsional vibration. A steel crankshaft will not distort like rubber, but it distorts enough to have torsional vibration.

f. Damping Torsional Vibration. To reduce or eliminate torsional vibration, devices variously called *crankshaft-torque impulse neutralizers*, *torsional balancers*, or *vibration dampers* are used. Essentially, all work in a very similar manner. They all employ a damper plate or flywheel that can have some movement independent of the crankshaft even though rotating with the crankshaft. This independent movement tends to oppose or absorb the winding and unwinding of the crankshaft, thereby opposing torsional vibration.

(1) One type of vibration damper is shown in figure 38. A metal damper flywheel is held on the crankshaft hub by a friction clutch. The friction clutch slips when sudden speed changes occur. For example, the crankshaft has been wound up and then starts to unwind. This gives certain sections of it a momentary increase in speed. The damper flywheel continues its steady rotation, however, since the friction clutch slips. This slipping action actually imposes a drag on the crankshaft, thereby damping out twisting vibration. Similarly, if the crankshaft receives an impulse that tends to wind it up, the vibration damper opposes the action. However, the amount of actual movement of the crankshaft as it winds up or unwinds is very small. But it would be sufficient to cause trouble if some type of vibration damper were not used.

(2) A second type of vibration damper makes use of a series of rubber cones, or sleeves, which support the damper plate, or damper flywheel, which presses against friction faces located on a fan pulley. The rubber compresses one way or the other so that the damper flywheel rubs against the friction faces, thereby, imposing a dragging restraint on the crankshaft during sudden speed changes. It acts in the same way as the friction clutch described in (1) above. Instead of rubber cones, a series of springs may be used.

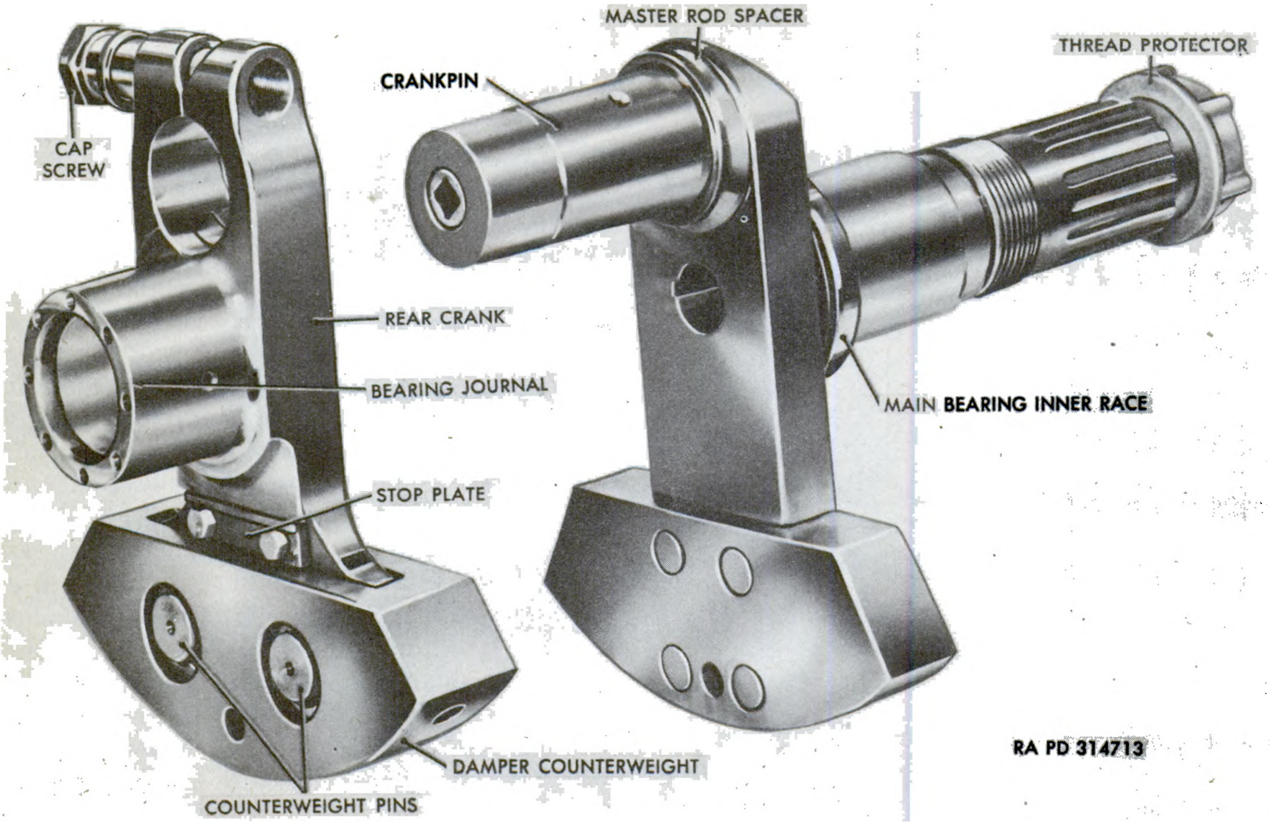


Figure 39. Radial engine crankshaft sections.

28. Crankshaft, Radial Engine

The crankshaft construction offers one of the pronounced differences between radial and in-line engines. Radial engine crankshafts are classified as to whether the crankthrow section is solid or of 2-piece construction, and as to the method of holding the sections together. There are three distinct types of crankshafts; solid crankpin or throw, split-clamp, and split-spline. The split-clamp type permits use of a solid big-end master-rod bearing designed to minimize distortion under heavy load; it is the most common of the three, and will be described in detail. It is a single-throw counterbalanced assembly machined from steel forgings.

a. The split-clamp-type crankshaft (fig. 39) has rear and forward sections. The forward section consists of the shaft proper, the front crank cheek with its counterweight, and the crankpin. The rear section of the shaft consists of the rear crank cheek with its counterweight and the rear main bearing journal. The crankshaft assembly is supported by two bearings. The connecting rods, called articulated rods, are attached to the crankpin through a single master rod as shown in figure 40. On some engines, a tail shaft is splined into the rear end of the crankshaft. On other engines, an accessory driving gear is mounted onto the rear end of the crankshaft. The crankshaft sections shown in figure 39 are of the latter type. In figure 39, the rear section is shown to the left and the front section to the right. A gear is mounted on the rear end of the crankshaft for driving the engine accessories. The gear (fig. 41) is made in two parts, the inside part being bolted to the crankshaft. Coupling with the ring gear is through springs which smooth out the power flow.

b. Radial engine firing impulses are heavy, and the connecting rods are concentrated on one throw. To counteract these heavy firing impulses, weights must be located opposite the throw where the forces of the connecting rods are exerted. Counterweights, forged as a unit with crankshaft sections or manufactured separately, provide the

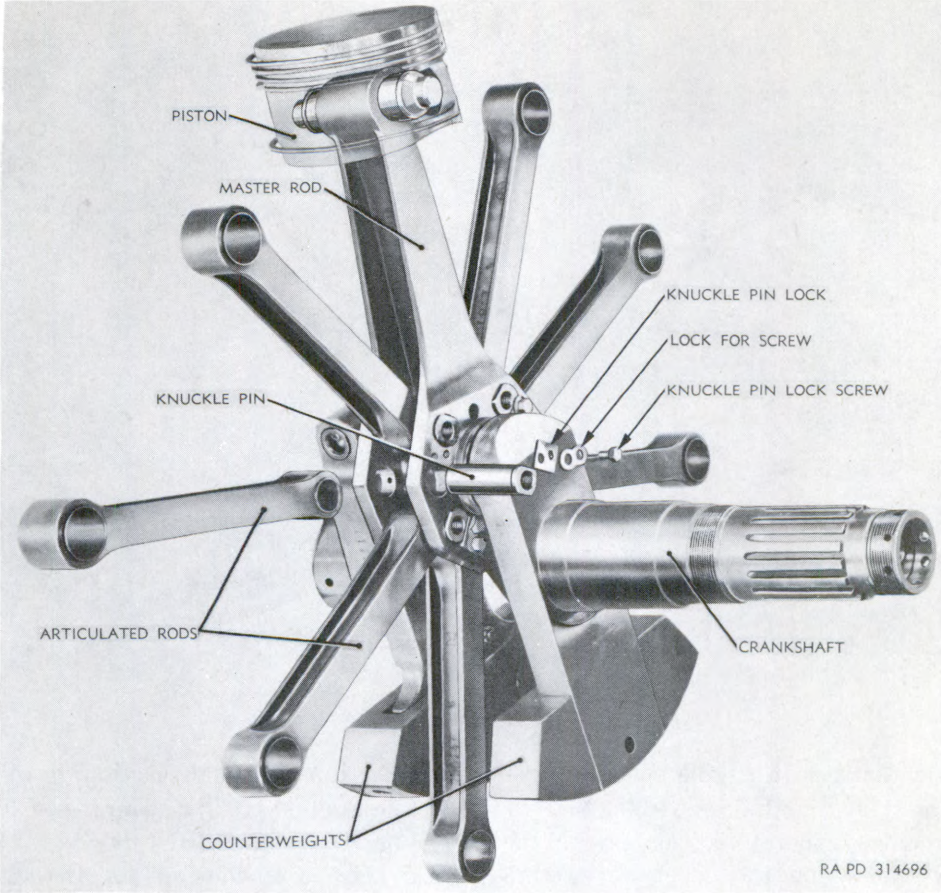


Figure 40. Radial engine crankshaft connecting rods and pistons.

necessary opposing force, easing the load on the bearings. If the weights are detachable, they may be made of either bronze or steel. Bronze, because of its greater weight, is preferable where space within the crankcase is limited. Bronze also has a greater damping effect on the engine impulses. If not integral parts of the section, the counterweights are riveted or bolted to the counterweight cheeks. They should be removed only under direction of the manufacturer.

c. As the power impulses in a radial engine occur several degrees apart, torsional vibration is set up in the engine. To damp these vibrations, the rear crankshaft counterweight is suspended on the crank cheek so that it acts as a free-swinging pendulum moving in the plane of crankshaft rotation. A typical damper consists of a movable slotted-steel counterweight attached to the crank cheek (fig. 42). Two spool-shaped pins extend into the slot and pass through oversized holes in both the weight and the crank cheek. This difference in diameter between the pins and the holes allows for the pendulum effect. The radius of the pendulum is so short that its frequency corresponds to that of the power impulses. The power impulses try to move the pendulum sideways in the plane of rotation, independently of the cheek, but this tendency is counteracted by centrifugal force due to crankshaft rotation. Centrifugal force moves the pendulum outward to the limit allowed by the difference in diameter between the pins and holes, and restores it to this position when the engine impulses try to move it sideways. The pendulum counterweight, therefore, applies counter-torque to each torque fluctuation caused by an engine impulse.

29. Flywheel

a. The flywheel (fig. 43) stores up energy of rotation when the instantaneous torque on the crankshaft is greater than average, and releases this energy when the torque is less than average.

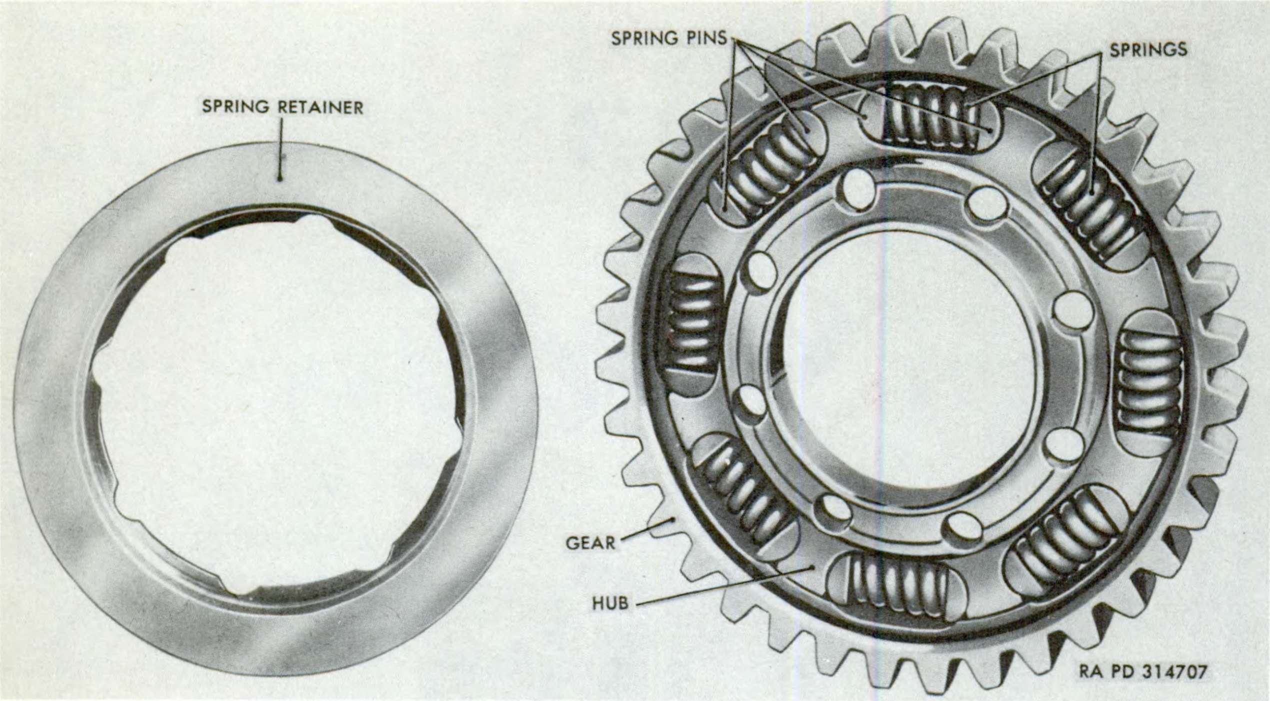


Figure 41. Radial engine crankshaft gear.

In this way, fluctuations in engine speed are reduced to within very small limits. The size of the flywheel required, therefore, varies with the number of cylinders and the general construction of the engine. With a large number of cylinders and the consequent overlapping of power impulses (par. 14*b*), there is less need for a flywheel; consequently, the flywheel can be relatively smaller. The flywheel rim carries a ring gear, either integral with the flywheel or shrunk on, that meshes with the starter driving gear for cranking the engine. The rear face of the flywheel is usually machined and ground, and acts as one of the pressure surfaces for the clutch, becoming part of the clutch assembly.

b. When used in aircraft, a radial engine does not require a flywheel because the propeller serves this purpose; when installed in an automotive vehicle, a flywheel is necessary. It is of cast-iron construction like that used in the in-line or V-type engines; but on the circumference, where the in-line engine has a ring gear to engage with the starter motor, the radial engine flywheel has a cooling fan (fig. 44). The flywheel is splined on the crankshaft where the propeller would be if the engine were in an airplane. There is no flange connecting the crankshaft and flywheel as in the conventional types. The splines act as a means of driving the flywheel. Longitudinal positioning of the flywheel on the crankshaft is accomplished by two cones, one on either side of the flywheel. The flywheel also acts as a housing for the clutch (if the vehicle has one) rather than employing a separate housing as the in-line engine does. Because the radial engine clutch is subjected to such high temperature in operation, there are holes in the flywheel to help in cooling the clutch.

30. Main Bearings

a. The crankshaft of an engine rotates in *main* bearings. These bearings are located at both ends and at certain intermediate points along the crankshaft. In in-line and V-type engines, the main bearings are supported by *webs* in the lower part of the cylinder block and, in high-speed automotive engines, these are the thin-shell bronze- or steel-backed type such as the main bearing shells shown in figure 36.

b. One-half of the shell fits into the cap. The upper half fits into fixed recesses in the lower part of the cylinder block. The two-part precision shell bearing is highly desirable because it can be easily replaced and does not require scraping and fitting. It has one principal disadvantage, however, in that it cannot be line-bored or reamed to allow for warpage of the crankshaft or block; if there is warpage, certain bearing areas

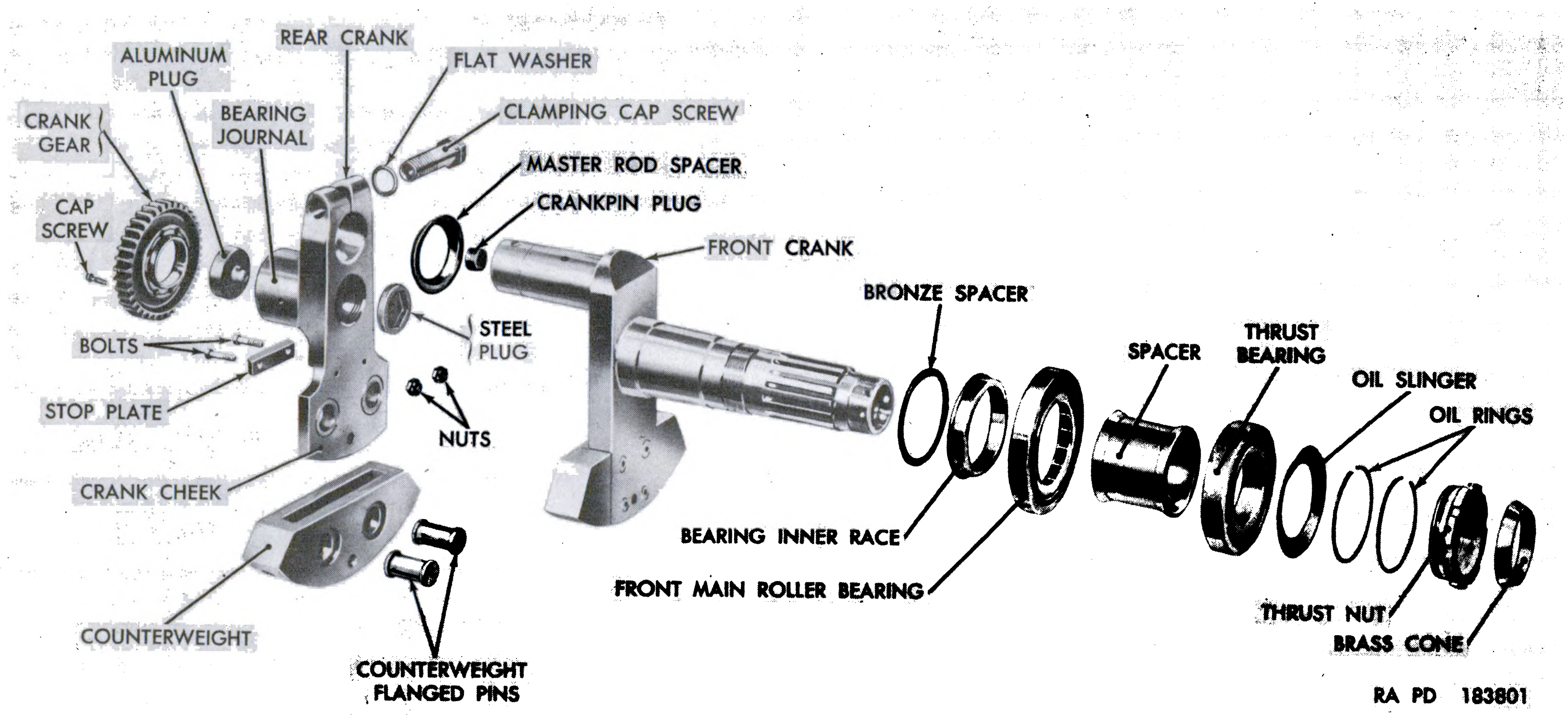

REAR CRANK
ALUMINUM PLUG
FLAT WASHER
CRANK GEAR
BEARING JOURNAL
CLAMPING CAP SCREW
MASTER ROD SPACER
CAP SCREW
CRANKPIN PLUG
FRONT CRANK
BRONZE SPACER
STEEL PLUG
BOLTS
THRUST BEARING
SPACER
OIL SLINGER
STOP PLATE
OIL RINGS
NUTS
CRANK CHEEK
BEARING INNER RACE
FRONT MAIN ROLLER BEARING
THRUST NUT
BRASS CONE
COUNTERWEIGHT
COUNTERWEIGHT FLANGED PINS
RA PD 183801

Figure 42. Radial engine crankshaft disassembled, showing counterweights.

are subjected to excessive wear. The precision bearing also is more expensive, but its advantages more than offset its disadvantages. The principal load on the main bearings is radial, but the small end-thrust load on the crankshaft is taken up by a main bearing which is provided with lip or thrust faces, and acts as a combination radial and thrust bearing, as the center main bearing shell in figure 36. The main bearings are often channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages, or by splash. To prevent loss of engine lubricating oil, oil seals are placed at the main bearings where the crankshaft extends through the crankcase.

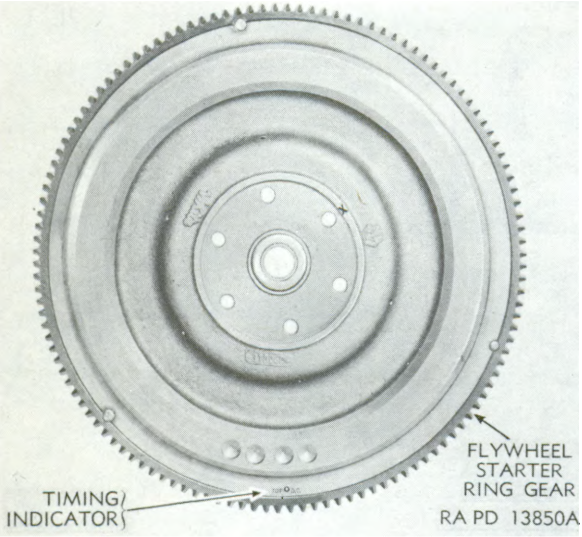


Figure 43. Flywheel.

c. Various combinations of main bearings have been used to support the crankshaft in radial engines. However, the arrangement common to radial engines in the automotive field makes use of two main bearings, one on either side of the crackshaft throw, and a third bearing located in the front section of the crankcase. The first main bearing is a roller bearing in the main bearing support section of the crankcase, where it takes the radial load produced by engine power impulses. The other main bearing is in the main crankcase section and is of the plain type. It also takes the radial load caused by engine impulses. Both main bearings are placed as near the crankshaft cheeks as possible to reduce chances of crankshaft deflection during operation. If the shaft were supported improperly and excess deflection occurred, dynamic unbalance would result. The third bearing is a ball thrust bearing designed to take the longitudinal thrust of the crankshaft.

31. Valves and Valve Seats

a. Valves. Every cylinder of any 4-stroke cycle engine must have at least one intake valve (fig. 1) to permit the mixture to enter the cylinder,

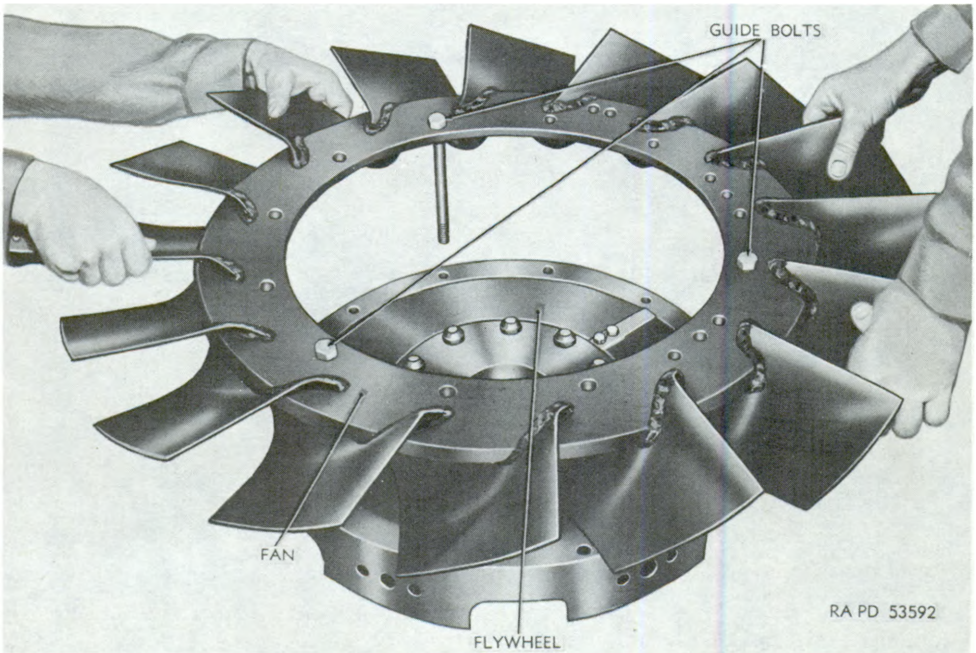


Figure 44. Radial engine flywheel, with cooling fan.

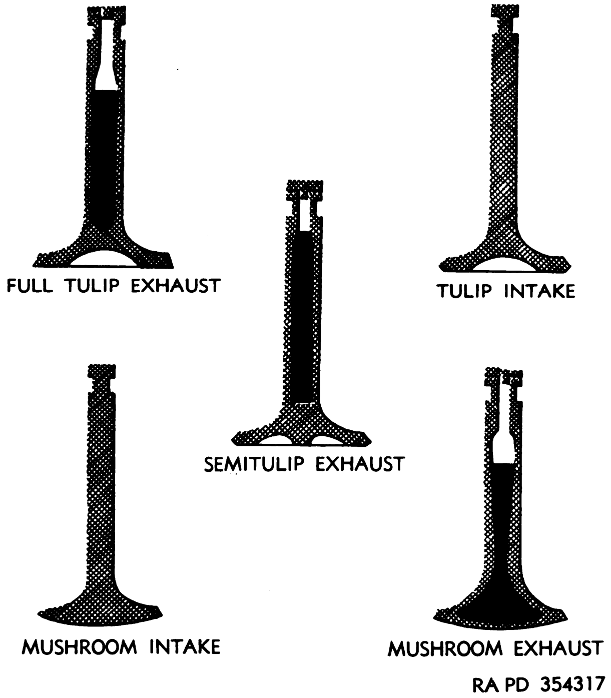


Figure 45. Valve types.

and one exhaust valve to allow the burned gases to escape (except for certain special designs which may utilize a single valve for both functions). The type of valve usually used in automotive engines is called a *poppet*, *mushroom*, or *tulip* valve (fig. 45). The world "poppet" is derived from the popping action of the valve, and the words "mushroom" and "tulip" from the general shape of the valve. A valve usually is made in one piece from special alloy steel. The intake valves ordinarily are made of chromium-nickel alloy and the exhaust valves of silichrome alloy because of the extremely high temperatures that they must withstand. In some engines, especially the air-cooled types, the exhaust valve contains sodium in a sealed cavity extending from the head through the stem, as shown in red in figure 45. The sodium conducts heat away from the head to the stem, from where it is conducted to the valve guide, thus aiding in cooling. When sodium-filled valves become unserviceable, dispose valves in accordance with existing regulations, since sodium will explode if it comes in contact with water.

b. Valve Seats. The valve seat is the face of the circular opening leading into the combustion chamber of the cylinder (fig. 1). There are at least two such openings, or ports, in each cylinder, to which are connected the intake and exhaust manifolds. Since exhaust valve seats are subjected to intense heat, valve grindings and reseatings are necessary from time to time to renew the seating surfaces. Regrindings can be minimized by using nickel-chrome cast-iron alloy in the cylinder castings or by using valve seat inserts. These inserts are rings of special alloy fitted into place in the cylinder block or cylinder head. Inserts can be used with both exhaust and intake valves, but are more frequently used with exhaust valves only.

c. Valve Guides. Valve stems are ground to fit the guides (fig. 46) in which they operate. The reamed hole in the guide must be alined and square with the valve seat to insure proper seating of the valve. The guides may be integral parts of the cylinder block or cylinder head, depending on the type of valves used, or they may be removable sleeves which can be replaced when worn. Removable valve guides are usually made of cast iron. Valve heads and seats are cooled by the transfer of heat to adjacent metals, which are cooled by the surrounding water.

32. Valve-Operating Mechanisms, In-Line, V-Type, and Opposed-Cylinder Engines

a. The valve-operating mechanism for one valve of an in-line, L-head engine is shown in figure 46. The camshaft is turned at one-half crankshaft speed by means of a pair of meshing gears (one on the crankshaft, the other on the

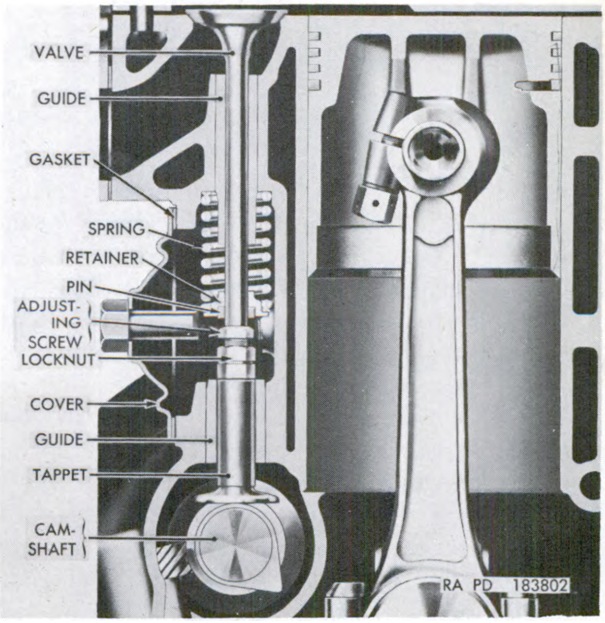
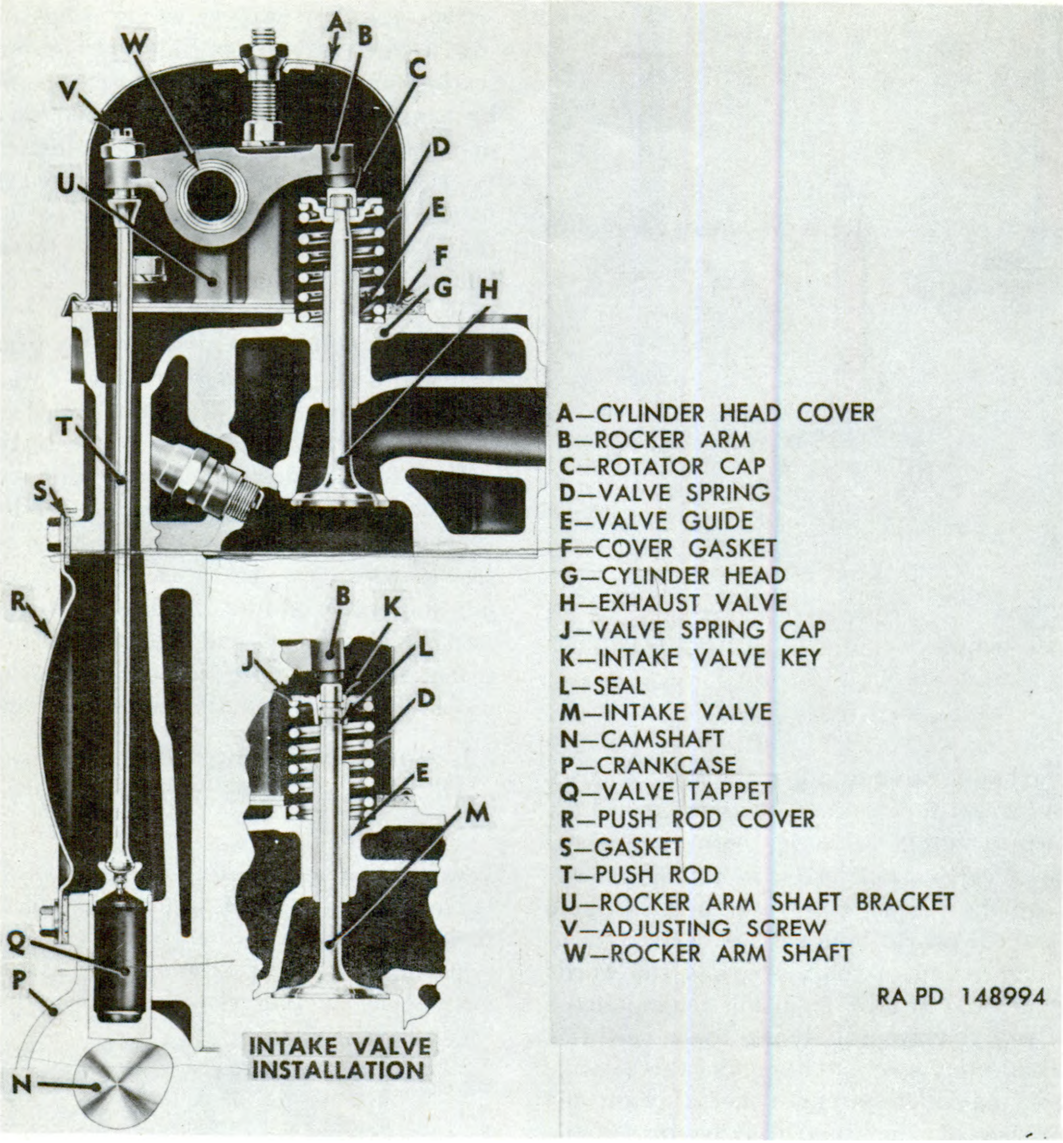


Figure 46. L-head valve-operating mechanism.



A—CYLINDER HEAD COVER
B—ROCKER ARM
C—ROTATOR CAP
D—VALVE SPRING
E—VALVE GUIDE
F—COVER GASKET
G—CYLINDER HEAD
H—EXHAUST VALVE
J—VALVE SPRING CAP
K—INTAKE VALVE KEY
L—SEAL
M—INTAKE VALVE
N—CAMSHAFT
P—CRANKCASE
Q—VALVE TAPPET
R—PUSH ROD COVER
S—GASKET
T—PUSH ROD
U—ROCKER ARM SHAFT BRACKET
V—ADJUSTING SCREW
W—ROCKER ARM SHAFT

Figure 47. Overhead valve mechanism.

camshaft), or by two sprockets and a chain. The camshaft has a cam for each valve. As the camshaft rotates, the cam lobe moves up under the valve tappet, exerting an upward thrust through the tappet against the valve stem. This thrust overcomes the valve spring pressure as well as gas pressure in the cylinder, causing the valve to be raised off its seat. When the lobe moves from under the tappet, the valve spring pressure reseats the valve.

b. The valve-operating mechanism of an in-line, valve-in-head (overhead valve) engine is shown in figure 47. In this arrangement, the valve tappet is raised by the cam lobe and this movement lifts the push rod. The rocker arm is thereby turned or rotated a few degrees on its shaft, causing the valve end of the rocker arm to move downward. This downward movement pushes the valve off its seat. Then, when the lobe moves from under the valve tappet, the valve spring pressure reseats the valve and also pushes the rocker arm back up in readiness for the next operation of the valve.

c. When the overhead valve arrangement is used in a **V**-type engine, both valve tappets and push rods operate off a single camshaft which is located above the crankshaft. That is, the push rods are located inside the **V** formed by the two banks of cylinders.

d. An overhead valve arrangement is also used

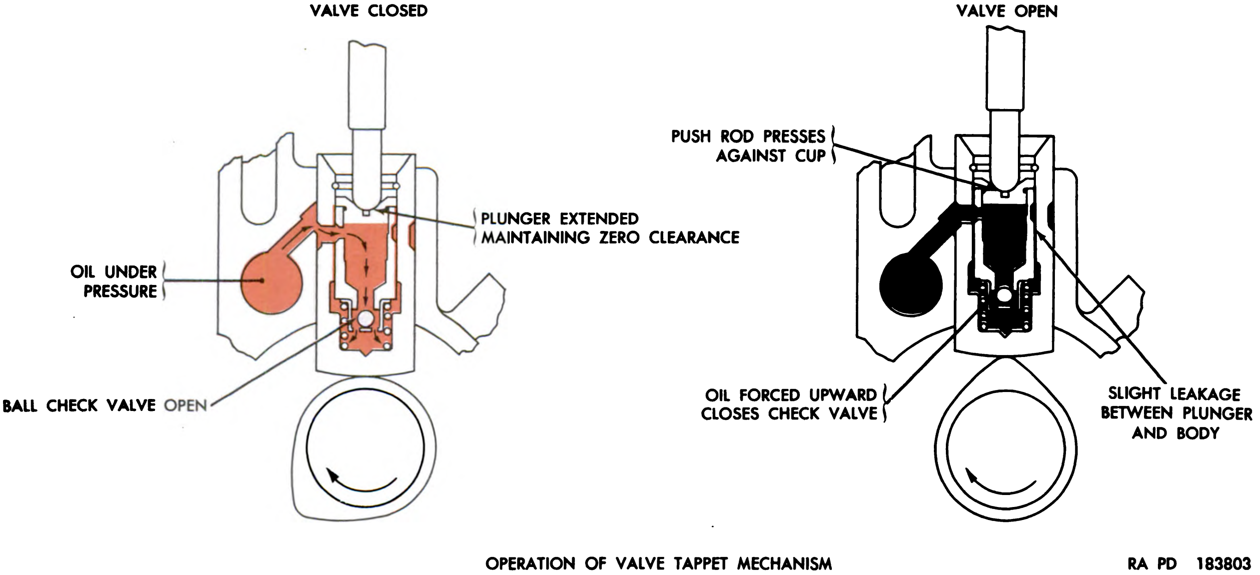

VALVE CLOSED
VALVE OPEN
PUSH ROD PRESSES AGAINST CUP
PLUNGER EXTENDED MAINTAINING ZERO CLEARANCE
OIL UNDER PRESSURE
BALL CHECK VALVE OPEN
OIL FORCED UPWARD CLOSES CHECK VALVE
SLIGHT LEAKAGE BETWEEN PLUNGER AND BODY
OPERATION OF VALVE TAPPET MECHANISM
RA PD 183803

Figure 48. Hydraulic valve, showing tappet action—cutaway views.

on opposed-cylinder engines, except that a separate camshaft operates each bank of opposed-cylinder tappets, push rods and rocker arms, and the camshafts in turn, are actuated by an accessory drive gear train.

e. Hydraulic valve tappets are used on many engines. The operation of one type of hydraulic valve tappet mechanism is shown in figure 48. Oil under pressure is forced into the tappet when the valve is closed, and this extends the plunger in the tappet so that all valve clearance, or lash, is eliminated. When the cam lobe moves around under the tappet and starts to raise it, there will not be any tappet noise. As the lobe starts to raise the tappet, the oil is forced upward in the lower chamber of the tappet. This action closes the ball check valve so oil cannot escape. Now, the tappet acts as though it were a simple, 1-piece tappet and the valve is opened. When the lobe moves out from under the tappet and the valve therefore closes, the pressure in the lower chamber of the tappet is relieved. Any slight loss of oil from the lower chamber is then replaced by the oil pressure from the engine lubricating system. This causes the plunger to move up snugly against the push rod so that any clearance is eliminated.

f. An overhead camshaft is used on some of the larger engines with overhead valves. The overhead camshaft eliminates the long linkages otherwise necessary in an overhead valve engine with a camshaft placed in the cylinder block. Figure 49 illustrates the valve mechanism of two cylinders in a 12-cylinder, V-type, air-cooled engine. A camshaft is required for each bank of cylinders. The camshaft cannot be seen in figure 49 because it is inside the intercylinder connectors. The inner ends of the rocker arms ride directly on the cams of the camshaft. As the lobe of a cam moves up under a rocker arm, the rocker arm rocks on its supporting shaft, causing the valve stem to be pushed down so the valve is opened. When the lobe moves on around out of the way, the valve spring pressure reseats the valve. In the application shown, the rocker arms have rollers on the camshaft ends. The rollers roll on the cams so that friction and wear are greatly reduced.

33. Valves and Valve-Operating Mechanism, Radial Engine

The poppet valve system is the prevalent type in radial engines, just as it is in in-line engines. The valves of a radial engine are opened positively by a cam ring, instead of by a camshaft as in the in-line engines, and are closed by spring action, as shown in figures 50, 51, and 52. The flow of the force opening the valves is as follows: the cam lobe works against a roller on the cam follower; the cam follower, in turn, forces the push rod up through a ball socket which fits in the top of the follower; and the push rod actuates the rocker arm assembly, which opens the valve by means of a roller acting on the tip of the valve stem. The cam followers are of hardened steel and are a close sliding fit in the follower guides to prevent oil leakage. The ball socket is also a

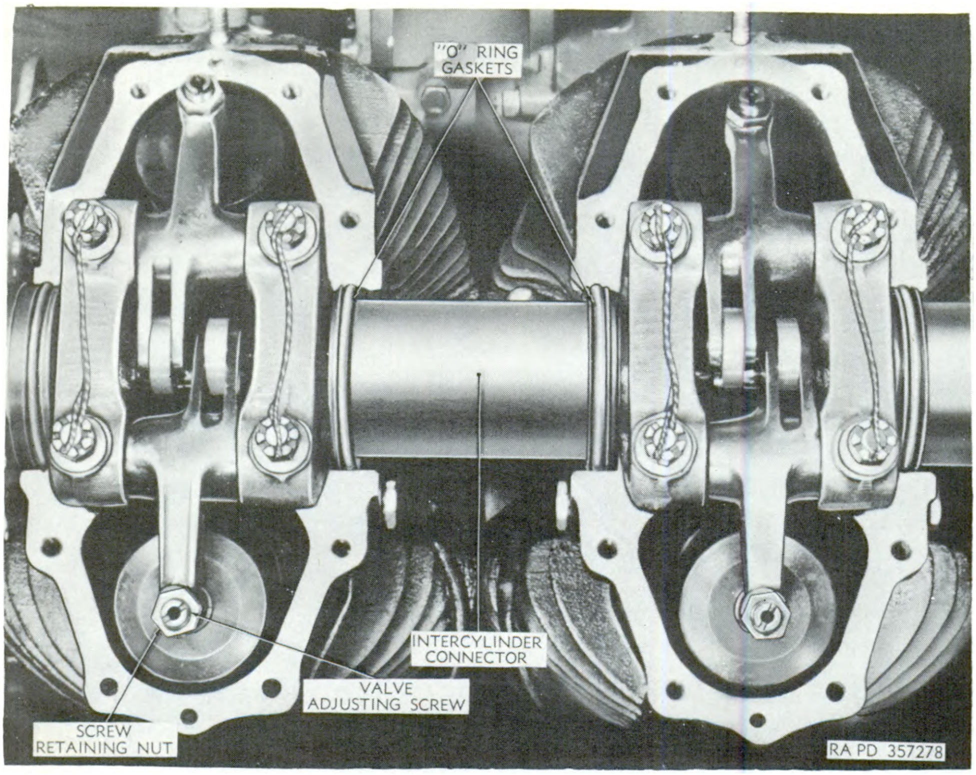


Figure 49. Valve mechanism of an overhead valve, overhead camshaft engine.

close sliding fit in the cam follower, and is held against the push rod by a coil spring in the cam follower.

a. The cam ring may be mounted on a shelf which is part of the crankcase construction, or on a sleeve which contains a hub of suitable bearing material. It is a unit made up of a hardened-steel ring with a double row of cam lobes, one for intake valves and one for exhaust, and either an external or internal spur gear. All parts of the unit are fixed and do not change position relative to each other. The number of lobes is determined by the number of cylinders and the direction of rotation of the cam ring. The spur gear is not connected directly to the crankshaft gear but is driven from a pinion on the starter shaft. In a 9-cylinder engine, the cam ring operates at about one-tenth or one-eighth crankshaft speed, the speed of rotation being determined by the direction of rotation of the cam ring in relation to the camshaft and the number of lobes on the cam ring. The cam-ring lobes have a ramp on each side to take up clearance in the push-rod assembly and to reduce the shock which occurs when the cam follower contacts the lobe. The clearance is caused by the elongation of the air-cooled cylinders due to the high temperatures of operation. As the cylinders elongate, they move the rocker boxes farther from the crankcase, but the length of the push rod increases only a small amount. The difference accounts for the clearance that is built up when the engine is hot. This must be taken into consideration in setting valve clearances, and explains why a radial engine must be warmed up properly before a load is applied. Otherwise, the valve timing would vary considerably from the specified requirements.

b. Except for size, radial engine valves are basically the same as those used in in-line engines, shown in figure 45. They are made of nickel-steel alloy forgings. The intake valve stem usually is much smaller than the exhaust valve stem, and is solid. Because it is exposed to large quantities of high-temperature gases, the exhaust valve is heavier; its stem is hollow and usually is filled with metallic sodium for cooling. The valves in a radial engine open and close rapidly and with more force than the ordinary in-line engine valves, so the mating surfaces on the valve faces and seats must resist more pounding. For these reasons, the seats are much wider than those of the in-line engine. In addition, the exhaust valve faces usually have a coat of stellite, an alloy highly resistant to heat and wear. A layer of stellite also is used on the

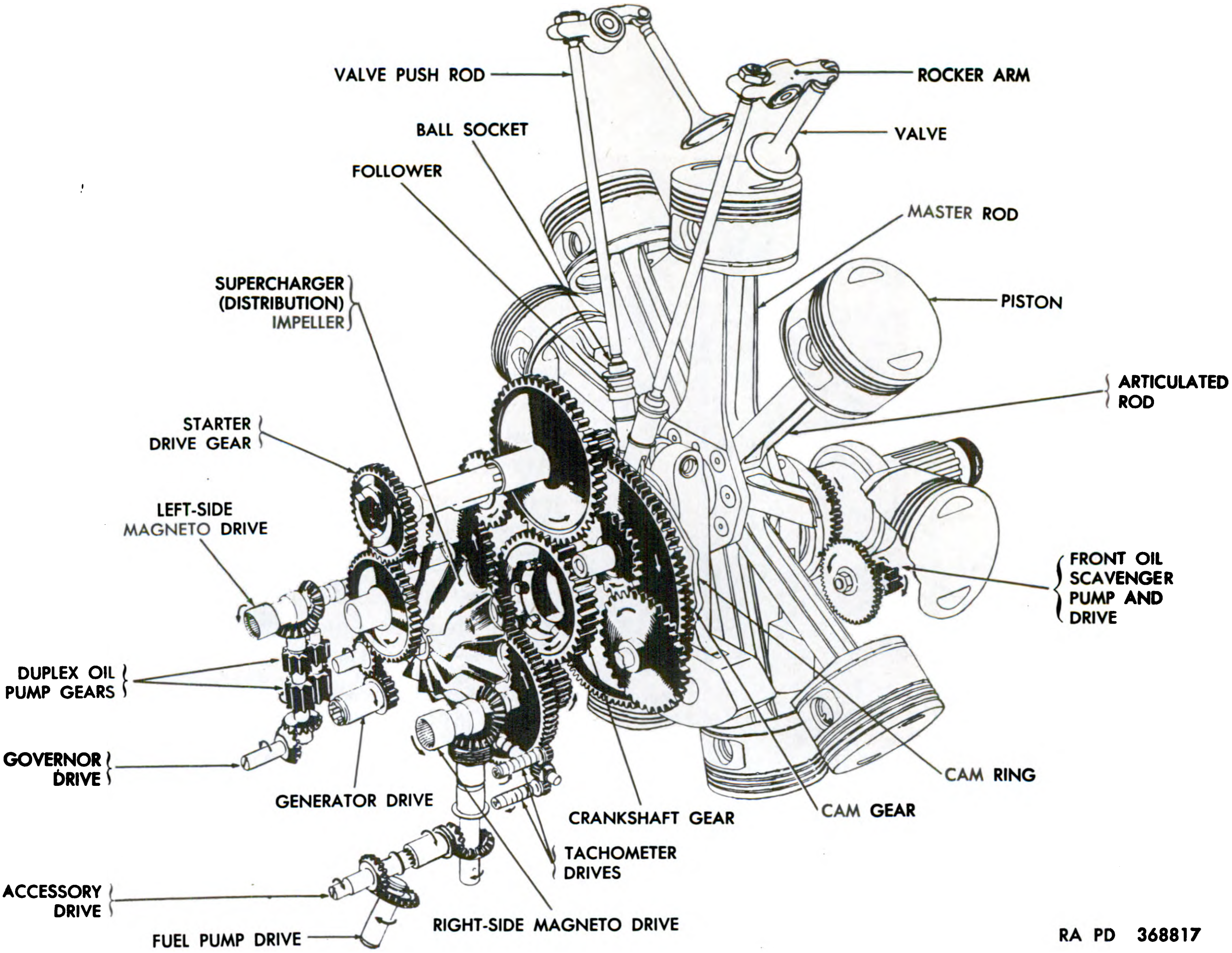

VALVE PUSH ROD
ROCKER ARM
BALL SOCKET
VALVE
FOLLOWER
MASTER ROD
SUPERCHARGER (DISTRIBUTION) IMPELLER
PISTON
ARTICULATED ROD
STARTER DRIVE GEAR
LEFT-SIDE MAGNETO DRIVE
FRONT OIL SCAVENGER PUMP AND DRIVE
DUPLEX OIL PUMP GEARS
GOVERNOR DRIVE
CAM RING
GENERATOR DRIVE
CRANKSHAFT GEAR
CAM GEAR
TACHOMETER DRIVES
ACCESSORY DRIVE
FUEL PUMP DRIVE
RIGHT-SIDE MAGNETO DRIVE
RA PD 368817

Figure 50. Radial engine gear trains.

tip of the valve stem where it contacts the rocker-arm roller. Most radial engine valves are of the "tulip" type, so called because of their tulip shape (fig. 45). The neck section is heavy, an aid in resisting higher temperatures, and the head is shaped so that stresses are more tensile. It uses a 45° face angle, which gives the advantage of better seating and heat-conducting qualities. Another recent type is the hollow-head mushroom valve. Its construction is supposed to eliminate any tendency of the valve to bounce, and it uses a 30° face angle, which gives better air-flow efficiency.

c. The valve springs are made of high-grade steel wire. They are wound in a helical shape with a flat coil on each end bearing against retaining washers. Two or three springs (fig. 52) are used to close the valves, although one would be enough if that were their only purpose; the additional springs prevent harmonic vibrations and bouncing of the valve, and are a safety factor.

34. Radial Engine Gear Train

A crankshaft gear (fig. 50) attached to the rear end of the crankshaft drives all engine accessories, including the valve-operating mechanism and impeller. The various gear trains are protected against the shock of sudden acceleration by a flexible-spring drive between the crankshaft and its gear. The crankshaft gear, impeller drive pinion, and the starter drive gear, all housed between the diffuser section and the main crankshaft section, mesh directly. The accessories, which include the magnetos, fuel pump, oil pump, tachometer, governor, and generator, are driven through idler gears that mesh with the starter drive gear. The shafts for these gears and the starter shaft extend rearward through the diffuser section to the rear or accessory section.

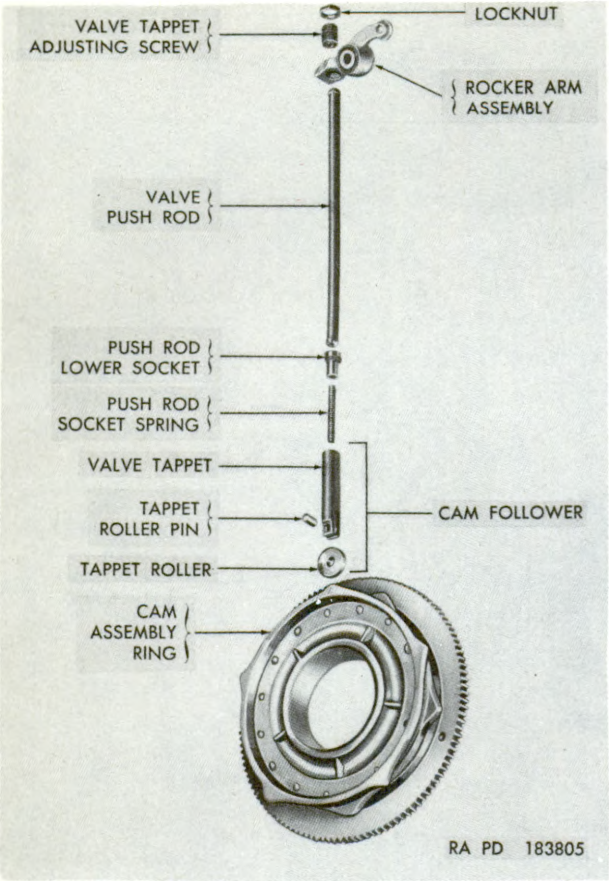


Figure 51. Radial engine valve-operating mechanism.

a. The starter drive gear is splined on the starter shaft. Gear and shaft are clamped together in most models by the starter shaft bolt, which carries the cam drive pinion on its forward end and passes through the entire length of the shaft. A spur gear at the rear of the starter shaft meshes through an idler gear with the generator drive.

b. The accessory drive shafts are of 2-piece construction, consisting of a separate shaft and separate magneto coupling which is a spline fit on the shaft. A screw through the center of the coupling is used for retaining it on the shaft. The magnetos are driven directly from these shafts. The right accessory drive shaft drives the tachometer drives, fuel pump drive, and right magneto drive. The left accessory drive shaft drives the oil pump and the left magneto drive. A 3-way accessory drive may be mounted on the engine accessory section in place of the fuel pump. On an airplane, it would be used for the fuel pump, vacuum pump, and propeller governor drives. However, only the fuel pump is required in automotive usage.

35. Power-Package Concept

a. The present trend in the design of military equipment is toward what is termed the *power-package concept.* That is, the equipment is so designed that the engine, together with the radiator, transmission, clutch, and other attached parts can be removed as a unit, or package, from the vehicle. This greatly facilitates repair and helps reduce "dead vehicle" time. When a vehicle requires major engine work, it is not necessary to tie up the vehicle while the work is done. Instead, the old power plant can be removed and a new one quickly installed. Figure 53 shows a typical power plant which has been removed with all its accessories as a unit, and is on an engine stand awaiting repairs. The radiator and engine-cooling parts are still on the engine. The engine has been removed wet, with coolant still in the cooling system and oil still in the crankcase.

b. To facilitate quick removal and installation of a power plant, the electrical system has quick-disconnect conduit plugs, and the various mounting bolts and mechanical linkages (to carburetor, clutch, transmission) are readily accessible. This greatly reduces the time needed to perform all disconnect operations.

36. Engine Families

To simplify the service parts problem in the field, and also to simplify servicing procedures, the present trend in military engine design is toward what are termed *engine families.* There must, of necessity, be many different kinds of engines because there are many kinds of jobs to do, from powering a tank to powering a ¼-ton truck; from running a large power plant to running a small auxiliary generator in a tank. However, the service and service parts problem can be simplified by so designing engines that they are closely related in cylinder size, valve arrangement, etc. As an example, one 800-hp engine uses the same connecting rod, piston, and piston rings as a similar but smaller 500-hp engine. As another example, an opposed-cylinder, 6-cylinder, air-cooled engine is rated at 500-hp supercharged or 375-hp nonsupercharged. Practically the only difference in these two engines, aside from the supercharger, is in the pistons. The 500-hp supercharged engine has pistons designed for a compression ratio of 5.5:1. The 375-hp nonsupercharged engine has differently shaped pistons which are designed for a higher compression ratio of 6.5:1.

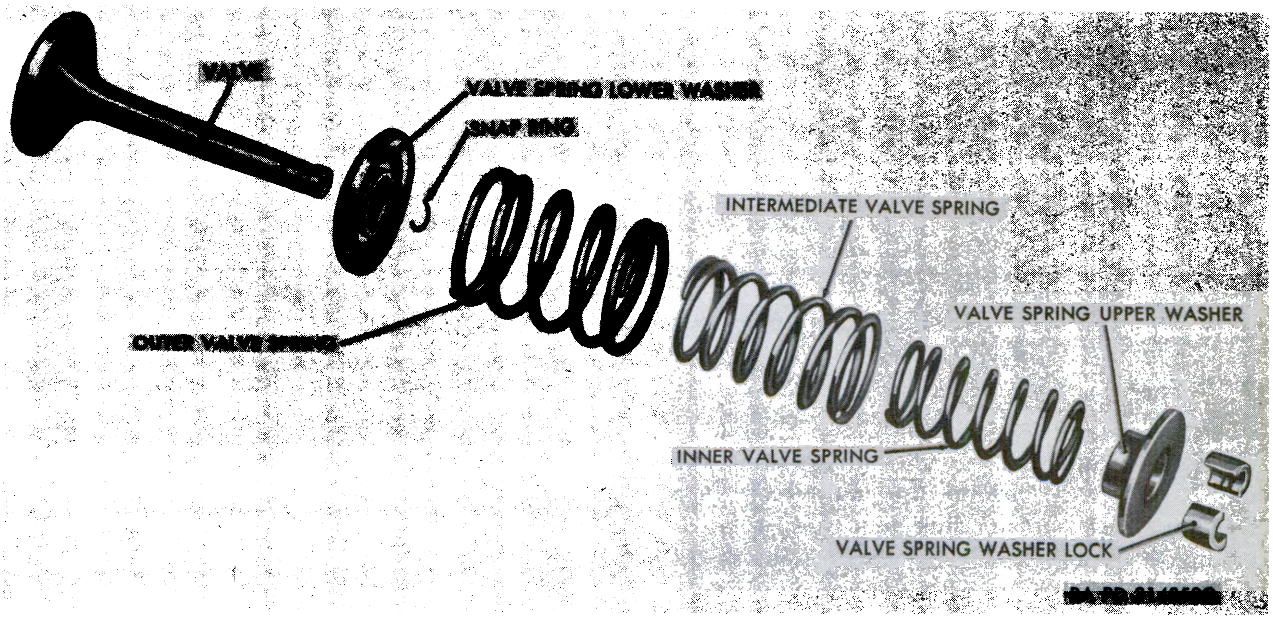

VALVE
VALVE SPRING LOWER WASHER
SNAP RING
OUTER VALVE SPRING
INTERMEDIATE VALVE SPRING
VALVE SPRING UPPER WASHER
INNER VALVE SPRING
VALVE SPRING WASHER LOCK

Figure 52. Radial engine valve and valve springs.

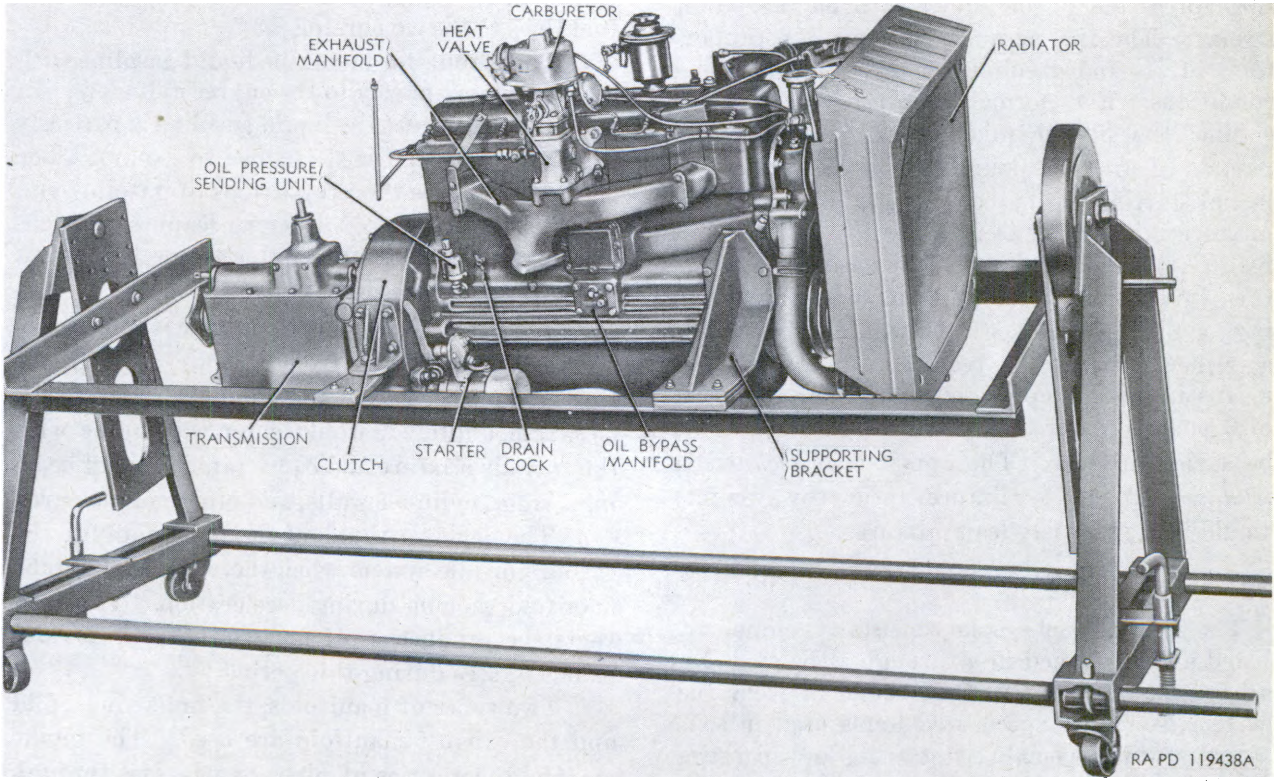

CARBURETOR
HEAT VALVE
EXHAUST MANIFOLD
RADIATOR
OIL PRESSURE SENDING UNIT
TRANSMISSION
CLUTCH
STARTER
DRAIN COCK
OIL BYPASS MANIFOLD
SUPPORTING BRACKET
RA PD 119438A

Figure 53. Power plant on engine stand.

CHAPTER 5

GASOLINE FUEL SYSTEMS

Section I. PURPOSE AND COMPONENTS

37. Purpose

The fuel system (fig. 54) supplies to the engine cylinders a combustible mixture of gasoline and air. It stores the gasoline in liquid form in a fuel tank, then converts this liquid into a vapor and mixes it with air. The mixture enters the engine cylinders on the intake strokes; it is then compressed and ignited. In burning, the fuel-air mixture increases in temperature, which causes it to expand, and a high pressure is therefore produced in the engine cylinders. This pressure forces the pistons downward on the power strokes. The fuel system must vary the proportions of air and gasoline for different operating conditions. For normal running with a warm engine, the proper mixture ratio is about 15 pounds of air to 1 pound of gasoline. But for initial starting with a cold engine, a much richer mixture is needed; the mixture does not burn as readily in a cold engine and the gasoline does not turn to vapor so readily. Also, when accelerating, or during high-speed or full-load operation, a richer mixture is required. *Richness* here means a higher proportion of gasoline; a mixture of 9 pounds of air to 1 pound of gasoline would be a rich mixture. The opposite of *richness* is *leanness*. A 15:1 mixture ratio (by weight) would be a relatively lean mixture.

38. Components

The gasoline fuel system consists of components listed and explained in *a* through *m* below. Not all the components listed are found in every fuel system; some are specialized items used in some vehicles with specialized starting or operating conditions.

a. The fuel tank stores the gasoline in liquid form.

b. The fuel lines carry the gasoline, in liquid form, from the fuel tank to the other components in the fuel system.

c. The fuel gage, a signaling system, indicates to the vehicle operator the amount of fuel in the fuel tank.

d. The fuel filter removes, from the liquid gasoline, dirt or particles that might otherwise get into other components of the fuel system or into the engine. Such particles could clog fuel passages in the carburetor, for example, and prevent normal fuel-system action.

e. The fuel pump, a mechanically or electrically operated device, pumps gasoline in liquid form from the fuel tank and delivers it through the fuel lines to the carburetor.

f. The carburetor mixes the liquid gasoline with air moving on its way to the engine cylinders. In this mixing process, the liquid gasoline is partially or completely vaporized (turned to vapor). The carburetor varies the proportions of gasoline and air so that mixtures of differing leanness or richness are supplied to the engine to meet different operating requirements.

g. The air filter, mounted on the carburetor, removes dust particles from the air as it passes through on the way to the engine. Those particles, if not filtered, would enter the engine with the fuel-air mixture and cause rapid wear of bearings, rings, cylinder walls, and other engine parts.

h. The degasser shuts off the fuel supply to the carburetor idle system when there is a high intake manifold vacuum during deceleration. This prevents the production of undesirable and noxious exhaust gases during this period.

i. Two types of manifolds, the intake manifold and the exhaust manifold are used. The intake manifold is a series of pipes or passages through which the fuel-air mixture from the carburetor is directed to the engine cylinders on the intake stroke. After the mixture is burned and the piston is moving up in the cylinder on the exhaust stroke (exhaust valve open), the burned gases are

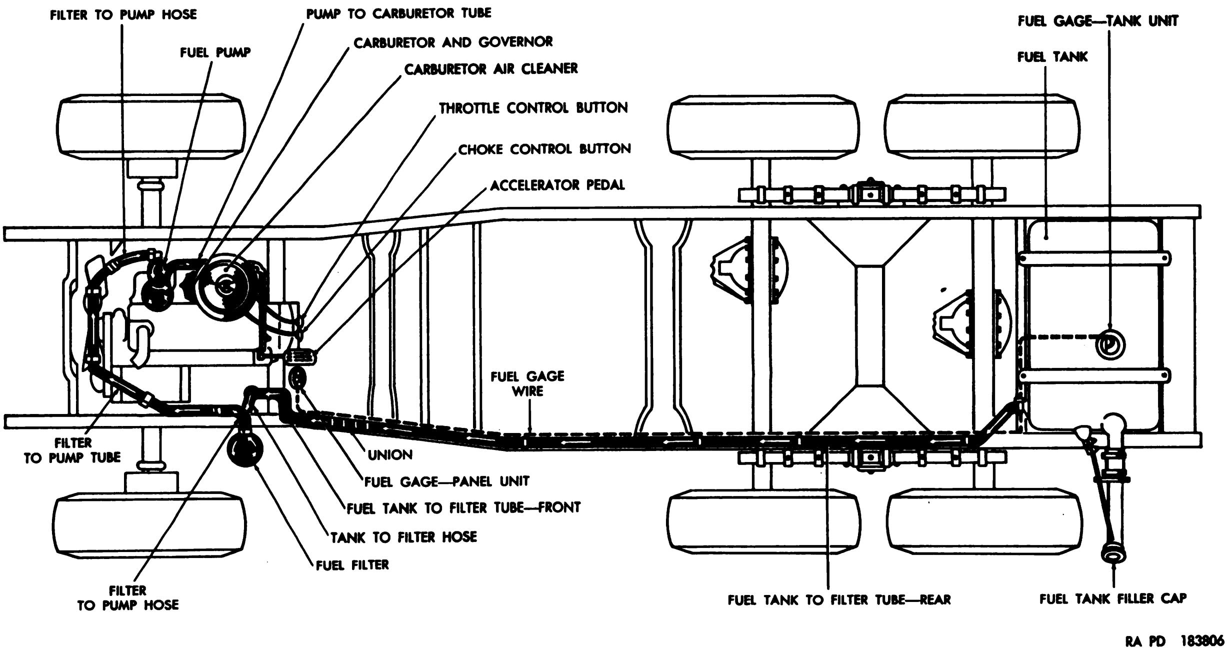

FILTER TO PUMP HOSE
FUEL PUMP
PUMP TO CARBURETOR TUBE
CARBURETOR AND GOVERNOR
CARBURETOR AIR CLEANER
THROTTLE CONTROL BUTTON
CHOKE CONTROL BUTTON
ACCELERATOR PEDAL
FUEL GAGE—TANK UNIT
FUEL TANK
FUEL GAGE WIRE
FILTER TO PUMP TUBE
UNION
FUEL GAGE—PANEL UNIT
FUEL TANK TO FILTER TUBE—FRONT
TANK TO FILTER HOSE
FUEL FILTER
FILTER TO PUMP HOSE
FUEL TANK TO FILTER TUBE—REAR
FUEL TANK FILLER CAP
RA PD 183806

Figure 54. Fuel system.

discharged into the exhaust manifold. From there, they pass through the muffler (which muffles the noise of the exhaust) and through the tail pipe into the open air.

j. The primer system, used on some applications to enrich the fuel-air mixture for starting, uses a hand-operated pump; this action sprays fuel into the intake manifold.

k. The governor, used on many vehicles, prevents overspeeding of the engine and consequent rapid engine wear. There are several types, but all produce essentially the same result. They cut down, or limit, the amount of fuel-air mixture going to the engine when engine speed tends to go beyond limits.

l. An injector system is used with some engines instead of a carburetor. With the injector system, a pump delivers fuel to a fuel injector. The injector then injects the proper amount of fuel into the intake manifold during the intake stroke.

m. The distributor impeller, used on radial engines or on engines with many cylinders, insures more uniform distribution of fuel-air mixture to the cylinders.

Section II. PRINCIPLES OF CARBURETION

39. General

Before discussing the various components of the fuel system in detail, the principles of carburetion and operation of the carburetor will be discussed to better understand how the other components of the fuel system function.

40. Composition of Air

Air is composed of various gases, mostly nitrogen and oxygen (78 percent, by volume, of nitrogen and 21 percent, by volume, of oxygen). These gases are, in turn, made up of tiny particles called *molecules.* All substances, whether solid, liquid, or gas, are made up of molecules. In solids, such as ice or iron, the particles are held very closely together so that they seem to have no motion. In liquids, the molecules are not held together so tightly, so they can move with respect to each other. Liquid can *flow.* In gases, there is still less tendency for the molecules to hold together and the molecules can therefore move quite freely. The molecules of a gas are attracted to the earth by gravity, or by their weight. It is the combined weight of the countless molecules in the air that we feel as atmospheric pressure (par. 10*c* (2)).

41. Evaporation

When a liquid changes to a vapor, it has evaporated. When this happens, molecules of the liquid move from the liquid into the air. As this continues, the liquid disappears from its container and appears as vapor in the air. The rapidity of evaporation varies with a number of factors. One of these is the volatility of the liquid (par. 42). Others include temperature, total pressure above the liquid, and amount of liquid that has already evaporated into the air above the liquid (degree of saturation).

a. The liquid (water in this instance) consists of molecules (par. 40). These molecules, not being closely tied together, move about. As they do so, they collide with each other. If a molecule happens to be moving upward rapidly enough, it will be able to jump clear of the liquid. As the molecules of liquid continue to do this, the liquid evaporates.

b. At higher temperatures, molecules move faster. This is true regardless of whether the molecules are in a solid, liquid, or gas. At low temperatures, the molecules move more slowly. But when a liquid is heated, molecules move more rapidly. This means that there are more fast-moving molecules escaping from the liquid. In other words, the rate of evaporation increases. This action can be easily seen in the process of boiling water. When this happens, the molecules are moving so rapidly that they escape in large numbers and in a violent manner.

c. When there is little gas (or atmospheric) pressure above the liquid, the molecules can escape from the liquid more easily. But when the pressure is high, it is more difficult for the molecules to escape and the rate of evaporation is decreased; some of the molecules from the liquid, as they escape from the liquid, collide with molecules of the air above. The collisions often knock the molecules back into the liquid. When the gas pressure is low, there are relatively few gas molecules above the liquid and relatively few collisions to knock the escaped molecules back into the liquid. But if the gas pressure is high, then there will be many more gas molecules and many more collisions that knock the escaped molecules back into the liquid. Thus, with high pressure above the liquid, the rate of evaporation is slowed down.

d. If the evaporation is taking place in a closed chamber, as for instance in a jar, evaporation of the liquid will soon stop; the closed space above the liquid will soon become "filled" with escaped molecules. These escaped molecules are in motion, just as all other molecules are moving. Some of the escaped molecules will be knocked *back into* the liquid. This action balances the escapes so that for every molecule that leaves the liquid, a molecule will re-enter the liquid. As a result, state of balance exists and evaporation can be said to have stopped.

42. Volatility

The term *volatility* refers to the ease with which a liquid vaporizes. Some liquids vaporize rather easily at room temperature. Alcohol, for instance, evaporates more easily than water. A highly volatile liquid evaporates very rapidly. A liquid of low volatility evaporates slowly. Gasoline is a mixture of several different fuels with varying degrees of volatility. High volatility is needed for easy starting when the engine is cold. But excessively high volatility will cause trouble after the engine warms up, or during operation in hot climates. The problem of gasoline volatility is dealt with in more detail in paragraph 47.

43. Atomization

Atomization means breaking a liquid into very tiny particles or globules. Atomization helps to turn a liquid into a vapor. If a spoonful of gasoline is put into a pan, it would take several seconds for it to evaporate, the length of time depending on temperature, volatility, and pressure (par. 41). However, if this spoonful of gasoline is put into an ordinary spray gun (fig. 55) of the type used to spray insecticides, the gasoline would be broken into a fine mist when operating the gun and this mist (composed of minute globules of liquid gasoline) would turn almost instantly into vapor. The reason for this is that a much greater area of the liquid is exposed to air when the gasoline is atomized. Evaporation takes place from all surfaces and increases with greater surface area.

44. Venturi Effect

a. A venturi is an hourglass-shaped restriction. In the carburetor (fig. 56), a venturi is

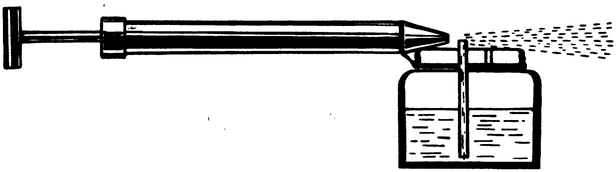


Figure 55. Spray gun.

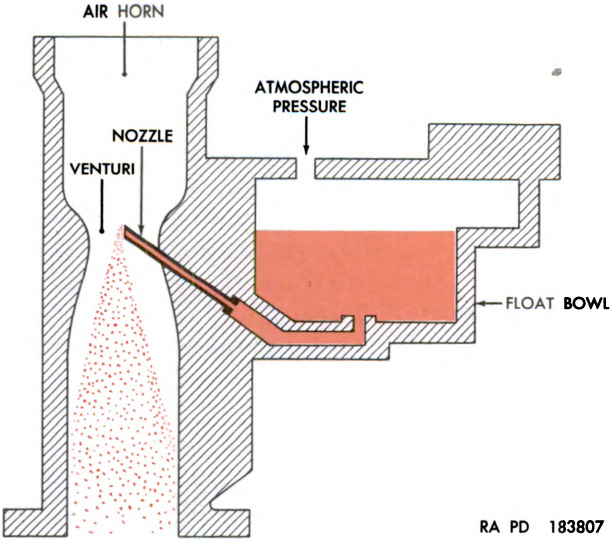


Figure 56. Simplified carburetor consisting only of air horn with venturi, float bowl, and nozzle.

placed in the air horn through which the air must pass on its way to the intake manifold and the engine cylinders. The purpose of the venturi is to create a partial vacuum (pressure less than atmospheric) at the outlet of the nozzle, which will permit atmospheric pressure on the surface of the gasoline in the float bowl to force the gasoline out through the nozzle. This gasoline then sprays and atomizes in the passing air to form the fuel-air mixture. It may seem like a contradiction to say that the restriction produces a vacuum, but, to learn how the vacuum is produced, examine the action of the air molecules as they pass through the venturi. As the molecules enter the carburetor air horn, they move down toward the venturi at uniform speed. However, as they approach the venturi, they must increase their speed if all molecules are to get through. That is, with the restriction, the molecules must move faster to get through.

b. The increased speed of the molecules produces a decrease in pressure (a partial vacuum). To understand this, it is necessary to know that the total energy of all things in nature remains constant, but this energy can change from one form to another form. Rubbing two sticks together to produce fire is an example of motion (one form of energy) being converted into heat (another form of energy). Also, if one form of energy increases, one or more other forms of energy must decrease, since the total energy remains constant. Thus, the increased speed (increased energy) of the molecules in a venturi produces a decrease in pressure (decreased energy); the increased speed also results in a decrease in temperature (decreased energy). Evaporation of the fuel further decreases the temperature (*c* below).

c. Since atmospheric pressure is admitted to the carburetor bowl, atmospheric pressure presses downward on the gasoline in the bowl. And, since there is less than atmospheric pressure in the venturi (where there is a partial vacuum), the atmospheric pressure pushes gasoline from the bowl, up through the nozzle and out into the passing air. The passing air breaks this stream of gasoline into small particles, thus atomizing it and speeding up its evaporation. In an actual carburetor, there may be several venturi, placed one inside another. They work together to improve fuel delivery and atomization of the fuel.

Note. **The evaporation of the fuel causes the temperature to decrease inside the venturi. Under certain conditions, the temperature is lowered to the point where ice may form in the carburetor.**

45. Other Carburetor Circuits

In addition to the basic venturi circuit described in paragraph 44, the carburetor has other circuits that vary the fuel-air ratio for different operating conditions. These circuits include the accelerating system, which momentarily enriches the mixture for improved acceleration when the throttle is opened; the maximum power circuit, which enriches the mixture when the throttle is opened wide for high-speed or full-load operation; the float system, for keeping a constant level of gasoline in the carburetor bowl; the idling circuit, for supplying an enriched mixture during engine idling, etc. All of these circuits are explained in detail in paragraphs 59 through 67.

Section III. CHARACTERISTICS OF GASOLINE

46. Source

Petroleum is the most common source of fuel for modern internal combustion engines. It contains two important elements (carbon and hydrogen) in such proportions that they will burn freely in air and liberate heat energy. Petroleum actually contains more potential energy than dynamite. Suppose a gallon of gasoline would drive a certain car 18 miles: the same amount of dynamite, if utilized as fuel, could drive the car only 3 miles. Gasoline is the most popular petroleum-base engine fuel because it is best suited to engine operation. It has many advantages, two of which are better rate of burning and easy vaporization to give quick starting in cold weather. Second in quantity used is diesel fuel, which is described in chapter 6. The major characteristics of gasoline that affect engine operation are volatility, purity, and antiknock quality.

47. Volatility in Gasoline

Volatility, as applied to gasoline, is its tendency to change from liquid to vapor at any given temperature. The volatility of gasoline affects ease of starting, length of warming-up period, and engine performance during normal operation. Rate of vaporization increases as the temperature rises and as surface pressure goes down (par. 41). Study volatility as it applies to automotive applications, with regard to starting ability, vapor lock, crankcase dilution, and fuel distribution.

a. Starting Ability. To start readily, an engine must have a burnable fuel-air mixture in the combustion chamber at the moment of starting. Ordinarily, the proper mixture is about 15 parts of air to 1 part of fuel by weight but, when an engine is cold, some of the vaporized fuel condenses and collects in the manifold. More fuel must be added to make enough fuel available for starting and operation until the engine reaches operating temperature. The fuel-air ratio may even be, under extreme conditions, as low as 1¼ : 1 to obtain 15 parts of air to 1 part of combustible fuel. This change in ratios is accomplished by the choke in the carburetor. Starting in cold weather is facilitated by using fuels of higher volatility.

b. Vapor Lock. Vapor lock is one of the difficulties experienced in using highly volatile fuels, especially in hot weather. When a fuel has a tendency to vaporize at normal atmospheric temperatures, it may form so much vapor in the fuel lines that action of the fuel pump results in pulsation of the vapor rather than a flow of fuel. To avoid vapor lock, heat-insulating materials or baffles are often placed between the carburetor and manifold or between the exhaust pipe and fuel line. Hot-weather grades of gasoline are blended from lower-volatility fuels to lessen the tendency toward vapor lock.

c. Crankcase Dilution. When cold weather or overchoking leaves an excessive amount of fuel unvaporized, another undesirable condition results. The fuel that is not vaporized seeps by the piston and piston rings and into the crankcase during the warming-up period. This dilutes the oil in the crankcase and reduces its lubricating qualities; the condition is known as crankcase dilution. It can be overcome if engine operating temperatures are high enough to cause the gasoline to be vaporized in the crankcase, the vapors being withdrawn through a ventilating system (par. 105).

d. Fuel Distribution. When fuel is not distributed evenly to all cylinders, the engine will run unevenly and power output will decrease. To insure good distribution, the fuel must be completely vaporized and mixed with air in the manifold before entering the cylinders. Quick, smooth acceleration also depends on a fully vaporized fuel-air mixture entering the combustion chamber.

48. Purity

Petroleum contains many impurities that must be removed during the refining process before gasoline suitable for automotive use is produced. At one time, considerable corrosion was caused by the sulfur inherent in petroleum products, but modern refining procedure has made it almost negligible. Another problem was the tendency for the hydrocarbons in gasoline to oxidize into a sticky gum when exposed to air, which resulted in clogged carburetor passages, stuck valves, and other operational difficulties. Chemicals that control the gumming tendency are now added to the gasoline. Dirt, grease, water, and various chemicals also must be removed to make gasoline an acceptable fuel.

49. Antiknock Quality

a. Combustion. To understand what is meant by antiknock quality, first review the process of combustion. When any substance burns, it is actually uniting in rapid chemical reaction with oxygen (one of the constituents of air). During this process, the molecules of the substance and oxygen are set into very rapid motion. In other words, heat is produced (since an evidence of heat is fast molecular motion). In the combustion chamber of an engine cylinder, the gasoline vapor and oxygen in the air are ignited and burn. They combine, and the molecules begin to move about very rapidly as the high temperatures of combustion are reached. The molecules, therefore, bombard the combustion-chamber walls and the piston head with a "rain" of fast-moving molecules. It is actually this bombardment that registers the heavy push on the piston and forces it downward on the power stroke.

b. Combustion Process. The normal combustion process in the combustion chamber (shown in red in fig. 57) goes through three stages that might be termed *formation of nucleus of flame*, *hatching-out*, and *propagation.*

(1) *Formation of nucleus of flame.* As soon as a spark jumps the gap of the spark-plug electrodes, a small ball of blue flame develops in the gap. This ball is the first stage, or nucleus of flame. It enlarges with relative slowness and, during its growth, there is no measurable pressure created by heat.

(2) *Hatching-out.* As the nucleus enlarges, it develops into the hatching-out stage. The nucleus is torn apart so that it sends fingers of flame into the mixture in the combustion chamber. This causes enough heat to give just a slight rise in temperature and pressure in the entire fuel-air mixture. Consequently, a lag still exists in the attempt to raise pressure in the entire cylinder.

(3) *Propagation.* It is during the third, or propagation, stage that effective burning occurs. The flame now burns in a "front" which sweeps across the combustion chamber, burning rapidly and causing great heat with an accompanying rise in pressure. This pressure causes the piston to move downward. The burning during normal combustion is progressive. It increases gradually during the first two stages, but, during the third stage, the flame is extremely strong as it sweeps through the combustion chamber. However, there is no violent or explosive action such as when detonation, ordinarily responsible for pinging, or knocking, occurs.

c. Detonation. If detonation takes place, it occurs during the third stage of combustion. The first two stages of burning are normal; but in the propagation stage, flame sweeps from the area around the spark plug toward the walls of the

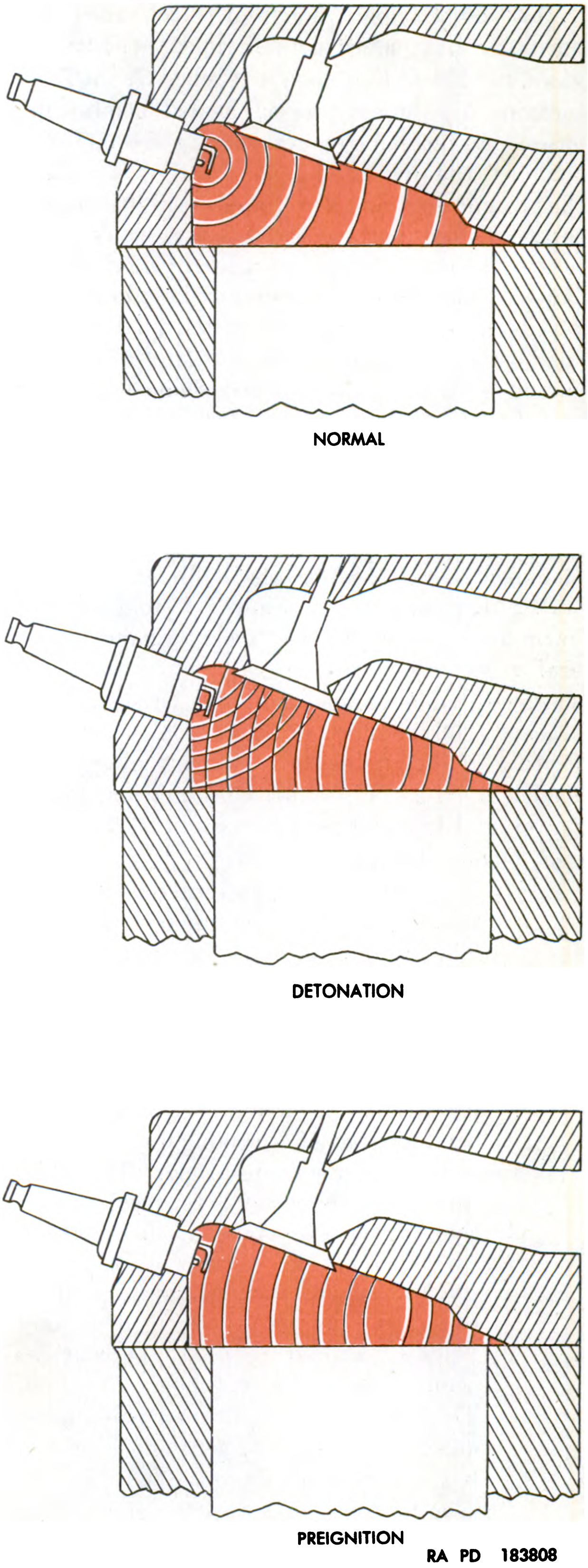


Figure 57. Combustion processes.

combustion chamber. Parts of the chamber that the flame has passed contain inert nonburnable gases, but the section not yet touched by the flame contains highly compressed heated combustible gases. As the flame races through the combustion chamber, the unburned gases ahead of it are further compressed and are heated to high temperatures. Under certain conditions, the extreme heating of the unburned part of the mixture may cause it to ignite spontaneously and explode. This rapid uncontrolled burning in the final stage of combustion is called *detonation* (fig. 57). It is caused by the rapidly burning flame front compressing the unburned part of the mixture to the point of self-ignition. This secondary wave front collides with the normal wave front and makes an audible knock. It is an uncontrolled explosion, causing the confined gases in the combustion chamber to rap against the cylinder and head walls. Knock, or ping, results. Detonation may harm an engine or hinder its performance in several ways. In extreme cases, pistons have been shattered, rings broken, cylinders burst, or heads cracked. Other effects of detonation may be overheating of the engine, broken spark plugs, overloaded bearings, high fuel consumption, loss of power, and frequent need for rebuild.

d. Octane Rating.

(1) The ability of a fuel to resist detonation is measured by its octane rating. The octane rating of a fuel is determined by matching it against mixtures of normal heptane and iso-octane in a test engine and under specified test conditions until a mixture of the pure hydrocarbons is found which gives the same degree of knocking in the engine as the gasoline being tested. The octane number of the gasoline is, then, the percent of the iso-octane in the matching iso-octane normal-heptane mixture. For example, a gasoline rating 75 octane is equivalent in its knocking characteristics to a mixture of 75 percent iso-octane and 25 percent normal heptane. Thus, by definition, normal heptane has an octane number of zero and iso-octane has an octane number of 100.

(2) The tendency of a fuel to detonate varies in different engines and in the same engine under different operating conditions. Octane number has nothing to do with starting qualities, potential energy, volatility, or other major characteristics. Engines are designed to operate within a certain octane range. Performance is improved with the use of higher octane fuel within that range if the spark setting is changed accordingly. However, if an engine operates satisfactorily at the upper limit of the octane-rating range of its fuel, it will not improve its performance to use fuel that exceeds the designed octane range.

(3) Tetraethyl lead is the most popular of the compounds added to gasoline to suppress knocking. Improved refining methods also have produced fuels of greater antiknock quality. Tetraethyl lead and other antiknock compounds are effective because they reduce the rate of burning of the fuel, thus, tending to prevent explosive burning or detonation. It takes only a small amount to produce the desired results. Most automotive fuels contain tetraethyl lead in amounts varying up to 3 cubic centimeters per gallon.

e. Other Causes for Knocking.

(1) Low-octane fuel is not the only reason for detonation. Anything which adds heat or pressure to the last part of the mixture to burn within a cylinder will aggravate detonation. That is why the compression ratio of a gasoline engine has an upper limit. When the ratio is raised too high the immediate result is detonation - due to the excessive heat caused by additional compression. Under certain conditions, preignition, excessive spark advance, lean fuel mixture, and defective cooling systems are a few of the many causes of detonation.

(2) Detonation is not to be confused with preignition (fig. 57). Detonation takes place late in the burning process after the spark has occurred. Preignition, however, is an igniting of the fuel-air mixture during compression before the spark occurs and is caused by some form of hot spot within the cylinder; for example, an overheated exhaust valve head, or hot spark plug, or an incandescent piece of carbon. Preignition

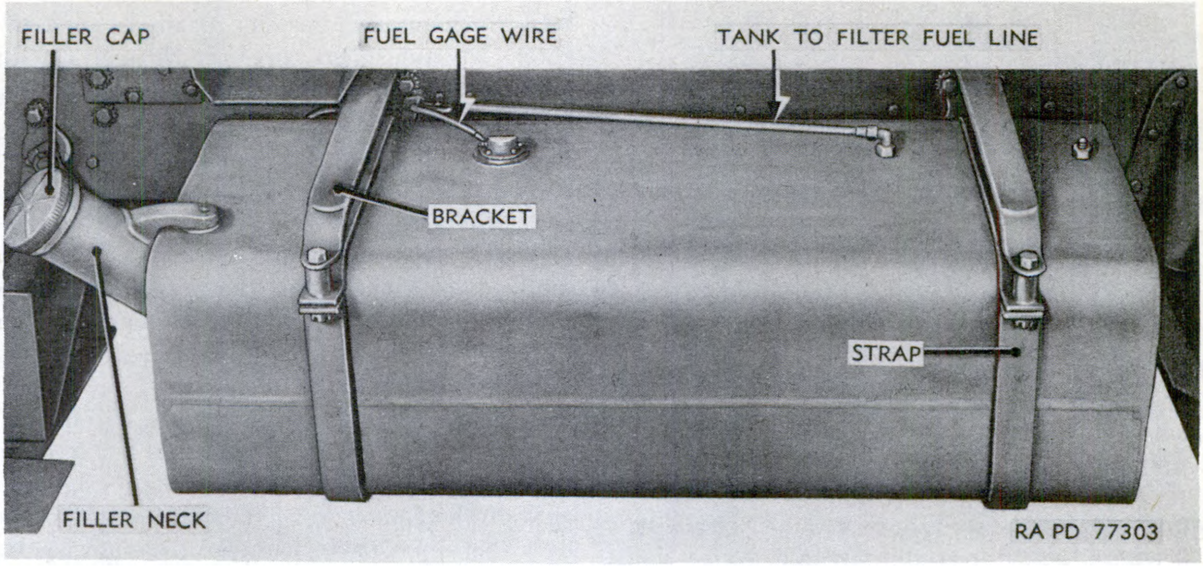


Figure 58. Fuel tank.

may lead to detonation, but the two are separate and distinct events.

50. Fuel Tanks and Gages on Tanks

a. The fuel tank (fig. 58) may be located at any convenient point on the vehicle. As fuel is supplied to the carburetor at pressure above atmospheric, the position of the tank has little effect upon the quantity of fuel forced into the carburetor. The tank, usually made of thin-gage metal, is covered with terneplate (lead and tin alloy) to prevent corrosion. It has an inlet for filling the tank and an outlet in the top or side leading to the fuel pump. The outlet pipe, fitted for the fuel-line connection, extends down into the tank to about one-half of an inch from the bottom. This prevents sediment that may accumulated in the bottom of the tank from being drawn into the fuel line. Baffle plates in the tank serve more than one purpose. They reinforce the sides and bottom, and they prevent fuel from surging or splashing, which would hasten evaporation, break the fuel down chemically, and produce static electricity. Notches or perforations in the baffle plates permit fuel to flow freely through the compartments. There is a drain plug for draining and cleaning the tank.

b. Many vehicles have more than one tank. On multiple-tank vehicles, the tanks are interconnected and each has a fuel shutoff valve so that either may be shut off. On many vehicles, the tanks are not vented through the tank caps, as is common in passenger cars, but through a special vent line from the top of the tank to a common vent for chassis components. This makes it possible for the vehicle to ford water well above the top of the fuel tank without water entering the tank through the vent. The tanks on some vehicles have been made self-sealing. On these, rubber latex (a soft, uncured rubber) is placed between inner and outer walls. A hole caused by a bullet or flying fragment is quickly sealed by the swelling of the rubber latex at the point of damage. Tanks contain fuel sending units which send electrical signals to gages on the vehicle dash and thereby indicate the fuel level in the tank. In addition, many vehicles make use of an electrical fuel pump mounted inside the tank.

51. Fuel Filter

The fuel filter may be located at any point between the fuel tank and the carburetor, but the most common type is usually located between the fuel tank and fuel pump.

a. The filter often is combined with the pump, especially if it is the sediment bowl type as shown in figure 59. Fuel enters the glass bowl and passes up through the filter screen before flowing through the outlet; any water and solid matter caught by the screen falls to the bottom of the bowl, where it can be removed.

b. Another type of filter (fig. 60) is made of a series of laminated disks placed within a large bowl which acts as a settling chamber for the

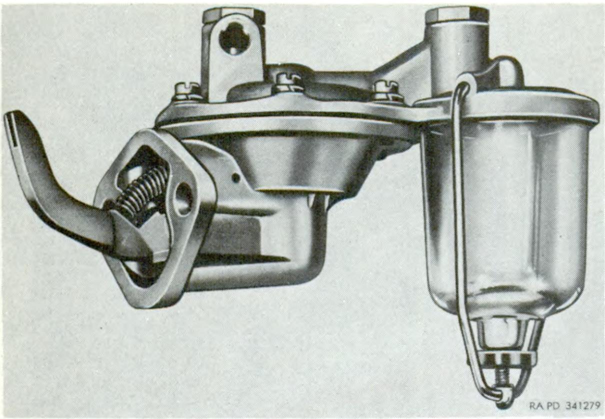


Figure 59. Fuel pump with attached filter bowl.

fuel and incloses the disks or strainer assembly. Fuel enters the filter at the top inlet connection and flows down, goes between the disks, and then up a central passage to the outlet connection at the top. Dirt and foreign matter cannot pass between the disks and are deposited at their outer rim. The clearance between the disks (0.003 inch) also is small enough to prevent the passage of water. This is possible because water, when present in gasoline, forms small globules that are too large to pass between the disks. Some commercial vehicles use filters with ceramic elements, but the metal disk type is the most common in military vehicles.

52. Fuel Pump

The fuel pump must deliver sufficient fuel to supply the requirements of the engine under all operating conditions. It must also maintain enough pressure in the line between the pump and carburetor to keep the fuel from boiling and to prevent vapor lock. Fuel pumps usually are classified as *positive* or *nonpositive*. The positive type (par. 80) continues to pump fuel even when the carburetor bowl is filled; therefore, a method of bypassing the fuel back to the supply tank must be provided. The nonpositive pump delivers fuel to the carburetor only when it is required.

a. The pump most widely used on gasoline engines is a diaphragm, nonpositive type. Ordinarily, it is actuated mechanically, although electricity may be used. The rotation of an eccentric on the camshaft actuates the rocker arm, which pulls the pump lever or link and diaphragm down against the pressure of the diaphragm spring (fig. 61). This reduces the pressure in the pump chamber, which permits gasoline from the tank to be forced by atmospheric pressure through the filter and inlet valve into the chamber. The diaphragm is moved up on its return stroke by the pressure of the diaphragm spring, and gasoline is forced through the outlet valve to the carburetor. When the carburetor bowl is filled, a back pressure is created in the fuel pump chamber, holding the diaphragm down against the pressure of the diaphragm spring. It maintains this position until the carburetor needs more gasoline. The rocker arm and the pump lever are in two pieces which operate as a single part when the diaphragm is moving up and down. However, when fuel is not required and the lower part of the rocker arm is held down at one end by the diaphragm pull rod, only the upper part operates in the normal way. This is possible because the rocker arm operates against the lower part only in the downward direction. Upward movement of both parts is by spring pressure. It is this feature of operation which makes the pump nonpositive.

b. Some mechanically actuated pumps have a vacuum booster (fig. 62) built in them to provide positive windshield-wiper operation at all times. This overcomes failure of the wiper on acceleration and under full throttle. The booster section operates the windshield wiper only; it has nothing to do with the fuel system except that it is

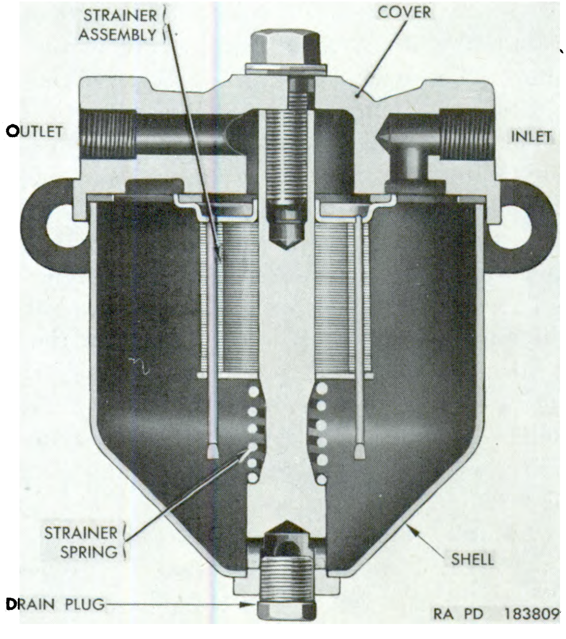


Figure 60. Fuel filter.

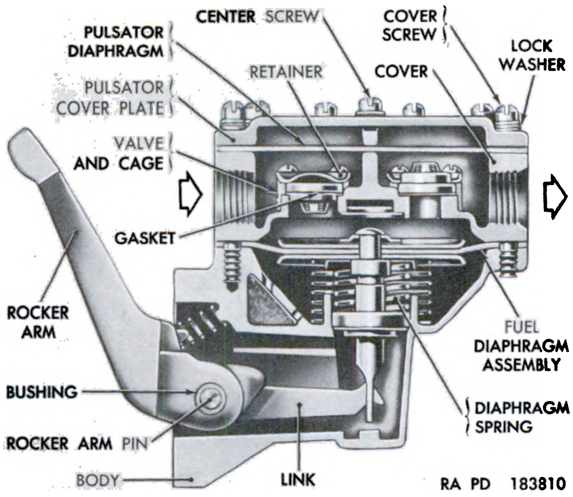

PULSATOR DIAPHRAGM
CENTER SCREW
COVER SCREW
LOCK WASHER
RETAINER
COVER
PULSATOR COVER PLATE
VALVE AND CAGE
GASKET
ROCKER ARM
FUEL DIAPHRAGM ASSEMBLY
BUSHING
DIAPHRAGM SPRING
ROCKER ARM PIN
BODY
LINK
RA PD 183810

Figure 61. Fuel pump—sectional view.

operated by the fuel-pump rocker arm. The booster-unit diaphragm is pushed down when the rotation of the camshaft eccentric actuates the rocker arm. Downward movement of the diaphragm expels air from the chamber through the exhaust valve which opens to the intake manifold. On the return stroke of the rocker arm, the spring moves the diaphragm up, creating a vacuum in the chamber and opening the intake valve. Air then comes through the inlet passage from the windshield wiper. When the wiper is not being used, atmospheric pressure holds the diaphragm down against spring tension. The diaphragm remains practically stationary, not making a complete stroke for every stroke of the rocker arm. When the intake manifold vacuum is greater than the vacuum caused by the pump, the air will flow from the windshield wiper through both

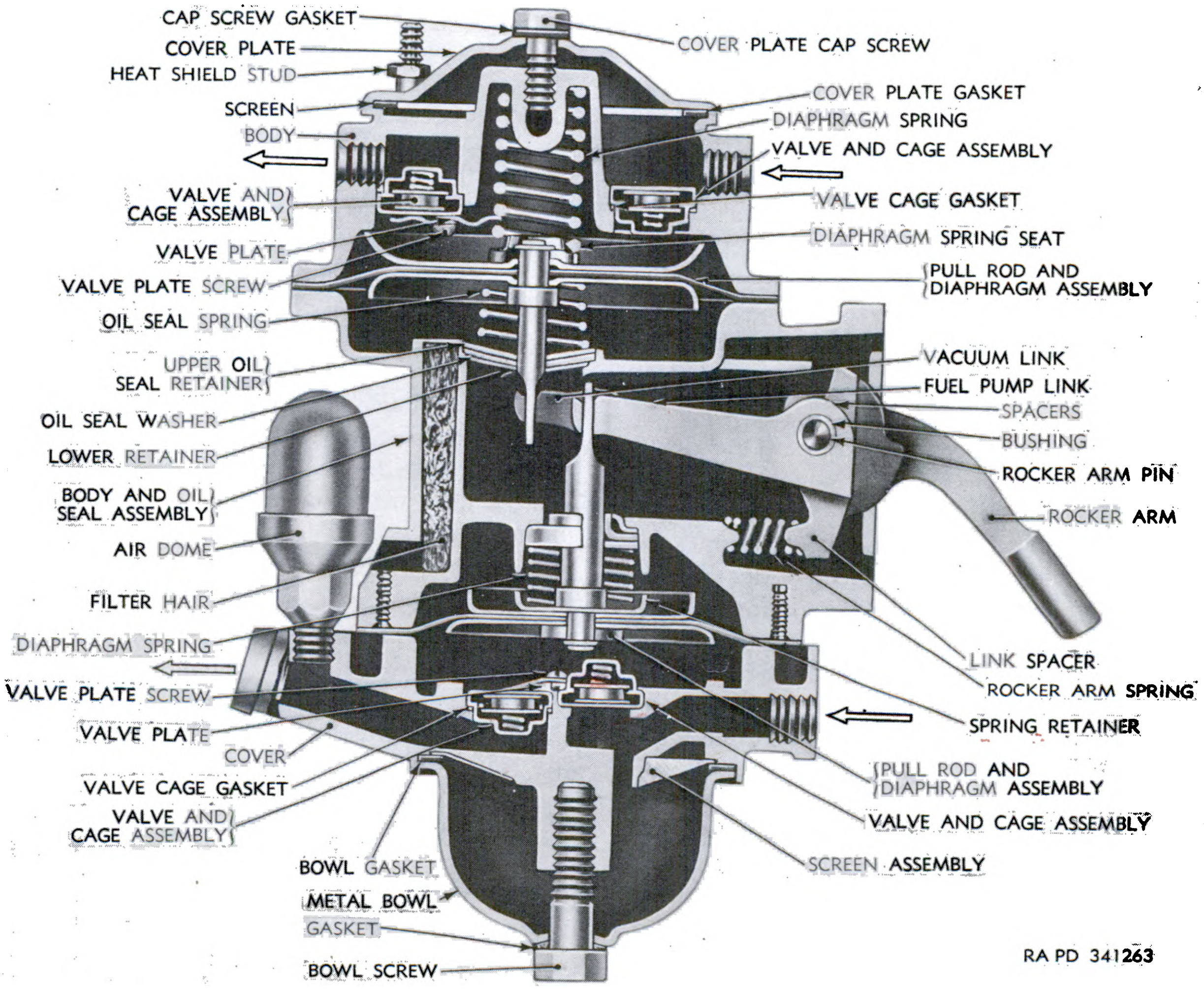

CAP SCREW GASKET
COVER PLATE
HEAT SHIELD STUD
SCREEN
BODY
VALVE AND CAGE ASSEMBLY
VALVE PLATE
VALVE PLATE SCREW
OIL SEAL SPRING
UPPER OIL SEAL RETAINER
OIL SEAL WASHER
LOWER RETAINER
BODY AND OIL SEAL ASSEMBLY
AIR DOME
FILTER HAIR
DIAPHRAGM SPRING
VALVE PLATE SCREW
VALVE PLATE
COVER
VALVE CAGE GASKET
VALVE AND CAGE ASSEMBLY
BOWL GASKET
METAL BOWL
GASKET
BOWL SCREW
COVER PLATE CAP SCREW
COVER PLATE GASKET
DIAPHRAGM SPRING
VALVE AND CAGE ASSEMBLY
VALVE CAGE GASKET
DIAPHRAGM SPRING SEAT
PULL ROD AND DIAPHRAGM ASSEMBLY
VACUUM LINK
FUEL PUMP LINK
SPACERS
BUSHING
ROCKER ARM PIN
ROCKER ARM
LINK SPACER
ROCKER ARM SPRING
SPRING RETAINER
PULL ROD AND DIAPHRAGM ASSEMBLY
VALVE AND CAGE ASSEMBLY
SCREEN ASSEMBLY
RA PD 341263

Figure 62. Fuel pump with vacuum booster.

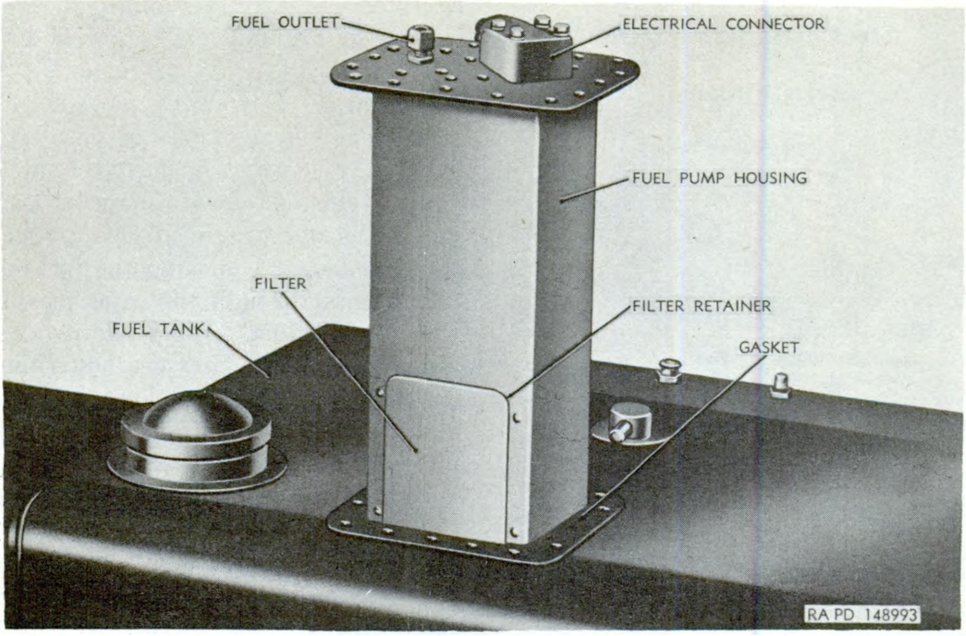


Figure 63. Fuel pump assembly—partially removed from fuel tank.

valves of the pump. Operation of the wiper is then the same as if there were no pump. It is when intake vacuum is low that the pump works. The vacuum it causes will then operate the wipers. This situation occurs during acceleration and at full-throttle speeds.

c. Several types of electric pumps are used.

(1) One type, the Autopulse, makes use of a metal bellows which is expanded by a solenoid when the unit is turned on (by turning the ignition key). This action draws gasoline from the fuel tank into the bellows. As the bellows reaches its limit of expansion, electrical contacts in the solenoid are tripped open and the solenoid releases the bellows. Spring pressure contracts the bellows. This contraction closes the intake valve in the pump and opens the outlet valve. Gasoline in the bellows is forced through the outlet valve to the carburetor. It can be seen that the bellows acts in the same manner as the diaphragm on the pumps described in *b* above.

(2) A second type of electric fuel pump is operated by an electric motor. The complete assembly is installed in a fuel-pump housing in the bottom of the fuel tank (fig. 63). The motor, as it runs, drives a pair of gears or a small impeller. The gear-type pump is much like the gear-type oil pumps used in engine lubricating systems (par. 101 *b*). The impeller-type pump is much like the water pump used in liquid-cooling systems (par. 89). Figure 64 illustrates an electric fuel pump of the impeller type.

d. The radial engine fuel pump is usually driven from the accessory-drive gear train, but may be driven by any one of several methods. The pump most commonly used is the eccentric sliding-vane type (fig. 65), although a diaphragm type has appeared on some of the later models. The two-vane positive-displacement spring-loaded pump, similar to that described in paragraph 80*b*, is the most commonly used vane type. It consists of an eccentric rotor into which are inserted two vanes pressed against the walls of the pump bore by a spring between the vanes.

53. Air Cleaner

Air cleaners are placed at the air intakes of carburetors to remove dust so that clean air is delivered to the cylinders. Dust is highly abrasive and can cause considerable damage to the pistons and the cylinder walls. Some air cleaners serve the additional purposes of arresting

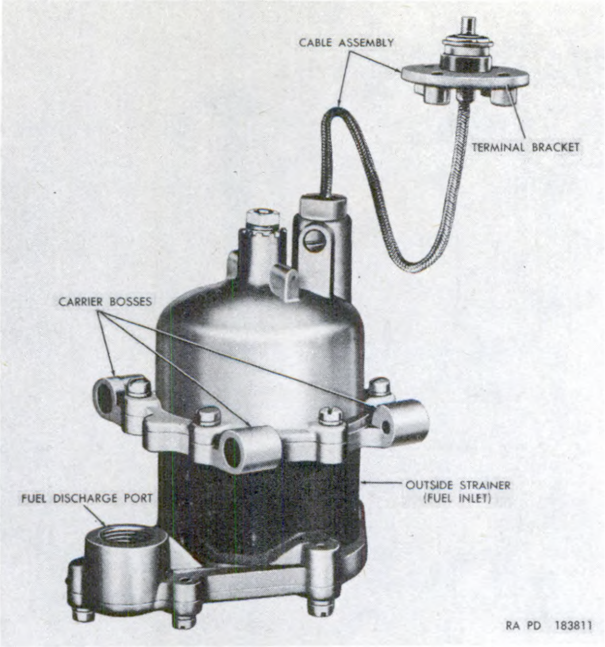


Figure 64. Electric fuel pump—impeller-type.

flames caused by carburetor backfire and muffling the hissing sound made by air entering the carburetor. Two types of air cleaners are used today, the wet type and the dry type.

a. Wet Type. The most common wet-type air cleaner (fig. 66) is the oil-bath cleaner, consisting of a main body, the filter element which is a unit filled with copper gauze, and a cover. Air entering the cleaner has to pass through small ports at the top of the main body and down between the main body and the copper gauze. Here, the air makes a 180° turn and passes over a bath of oil. It then passes up through the oil-soaked copper gauze, where the fine particles are filtered out. The air itself soaks the copper gauze with the spray it picks up as it passes over the oil bath. After the air passes through the copper gauze, it hits the cover plate and is deflected down through a passage to the carburetor.

b. Dry Type. The ordinary dry-type air cleaner (fig. 67) uses a copper gauze cleaner element. Others employ inertia and centrifugal principles. The dry-type air cleaner consists of a body, baffle plates to silence incoming air, loosely knitted copper gauze, and a cover plate with a felt pad. The incoming air passes through a series of baffles, where dust and dirt are removed, and then out into the carburetor.

c. Radial Engine Air Cleaners. The radial engine is equipped with two oil-bath air cleaners, similar to those described in *a* above. Air enters the cleaners through the upper air-intake tubes, passes through a stationary and a prefilter element, is cleaned by the oil in the oil cup, and is passed out through the lower intake tubes to the carburetor. The dirt collected drains to the bottom of the oil cup.

54. Intake Manifold

a. The intake manifold (fig. 68) distributes fuel as evenly as possible to each cylinder, helps to prevent condensation, and assists in further vaporization of the fuel mixture. Smooth and efficient engine performance depends on whether mixtures that enter each cylinder are uniform in strength, quality, and degree of vaporization. That is partly the job of the intake manifold. The ideal fuel-air mixture is completely vaporized when it goes into the combustion chamber. Complete vaporization requires high temperature, and high temperature increases volume and decreases the volumetric efficiency of the engine. Therefore, the best alternative is to introduce a fuel-air mixture into the manifold that is vaporized above the point where fuel particles will be deposited and below the point where excess heat results in power losses. Intake manifolds must be designed carefully to help meet these requirements. When two cylinders fire consecutively, the intake manifold must prevent fuel from being cut off from the cylinder firing second. This cutoff would be caused by the pressure differential set up by the intake of the first cylinder that fired. The walls of the manifold must be smooth and offer no obstruction to the flow of the fuel-air mixture. Design also should prevent collecting of fuel at the bends in the manifold.

b. The intake manifold should be as short and as straight as possible to reduce the chances of

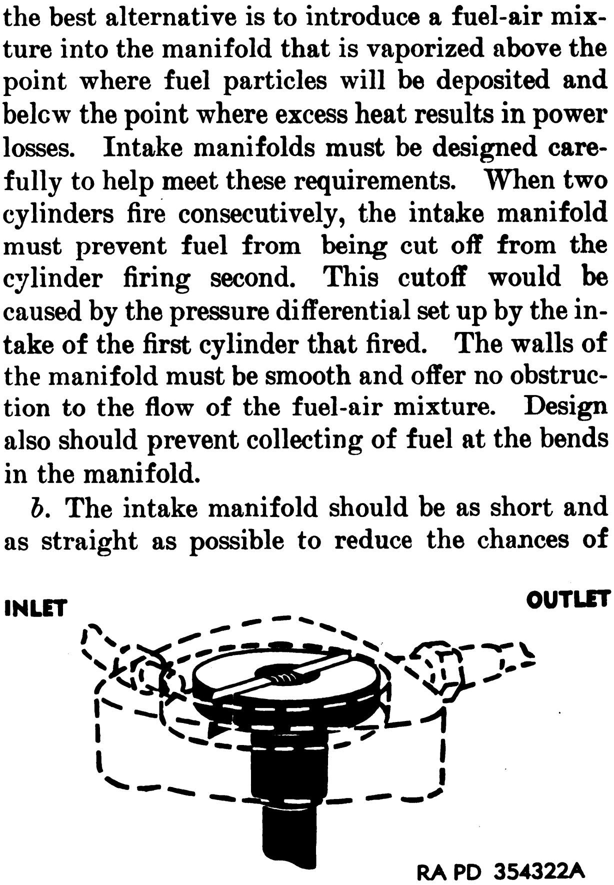


Figure 65. Vane-type fuel pump.

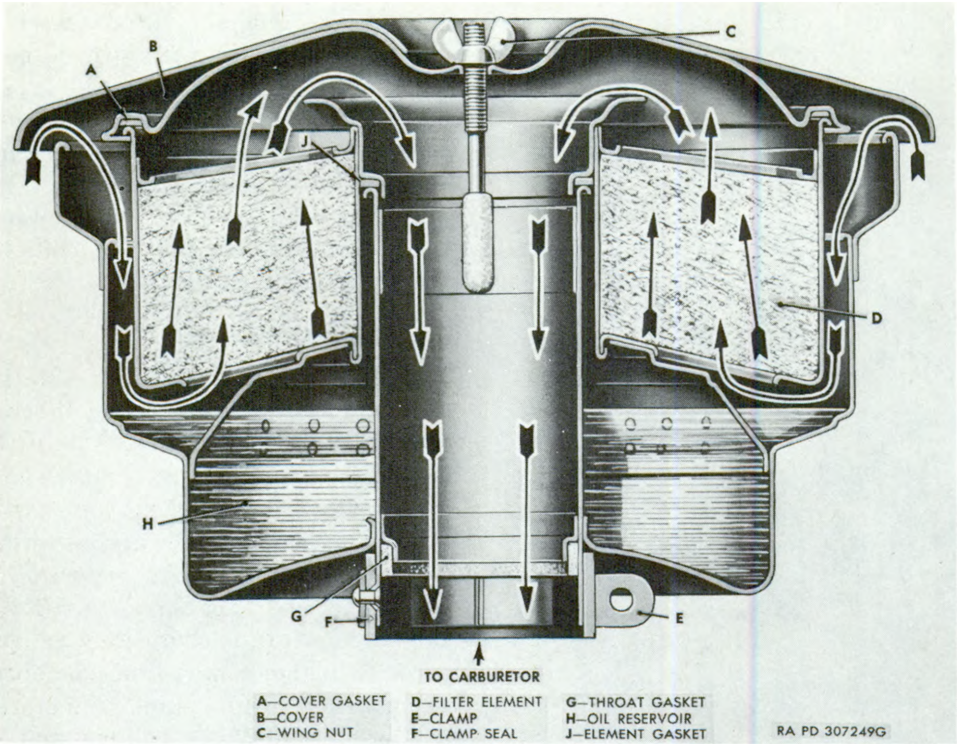

A
B
C
J
D
H
G
F
E
TO CARBURETOR
A—COVER GASKET
B—COVER
C—WING NUT
D—FILTER ELEMENT
E—CLAMP
F—CLAMP SEAL
G—THROAT GASKET
H—OIL RESERVOIR
J—ELEMENT GASKET
RA PD 307249G

Figure 66. Wet-type air cleaner.

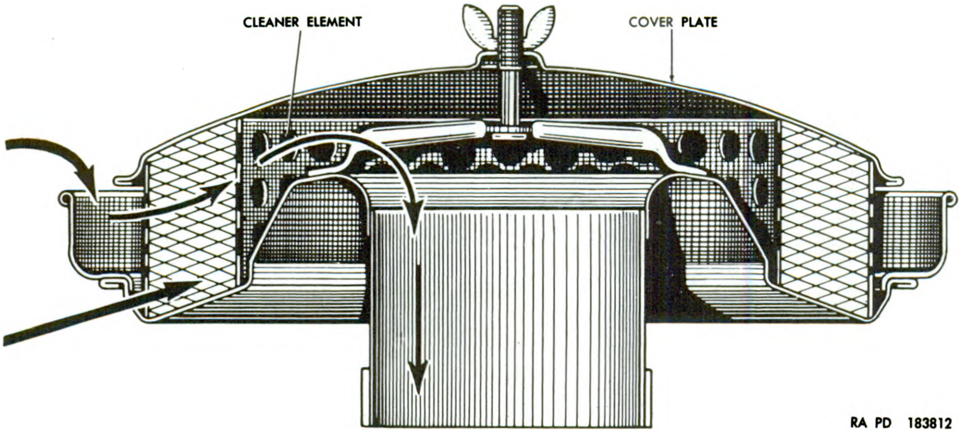

CLEANER ELEMENT
COVER PLATE
RA PD 183812

Figure 67. Dry-type air cleaner.

condensation between the carburetor and cylinders. To assist in vaporization of fuel, some intake manifolds are constructed so that part of their surfaces can be heated by hot exhaust gases. A valve is placed in the exhaust manifold, which deflects the gases toward the hot spot in the intake manifold (fig. 69) when the temperature around the engine is low. As the hot exhaust gases pass around the section of the intake manifold, the intake manifold is heated and the incoming fuel-air mixture is also heated. This helps to vaporize the fuel, a particularly important action in cold conditions when fuel vaporization is slow. When the engine begins to warm up, a thermostat attached to the heat control valve begins to turn the valve. When the temperatures are sufficiently high to assure adequate vaporization of the incoming fuel, then the valve has turned to the position shown to the right in figure 69. In this position, the hot exhaust gasses are directed downward

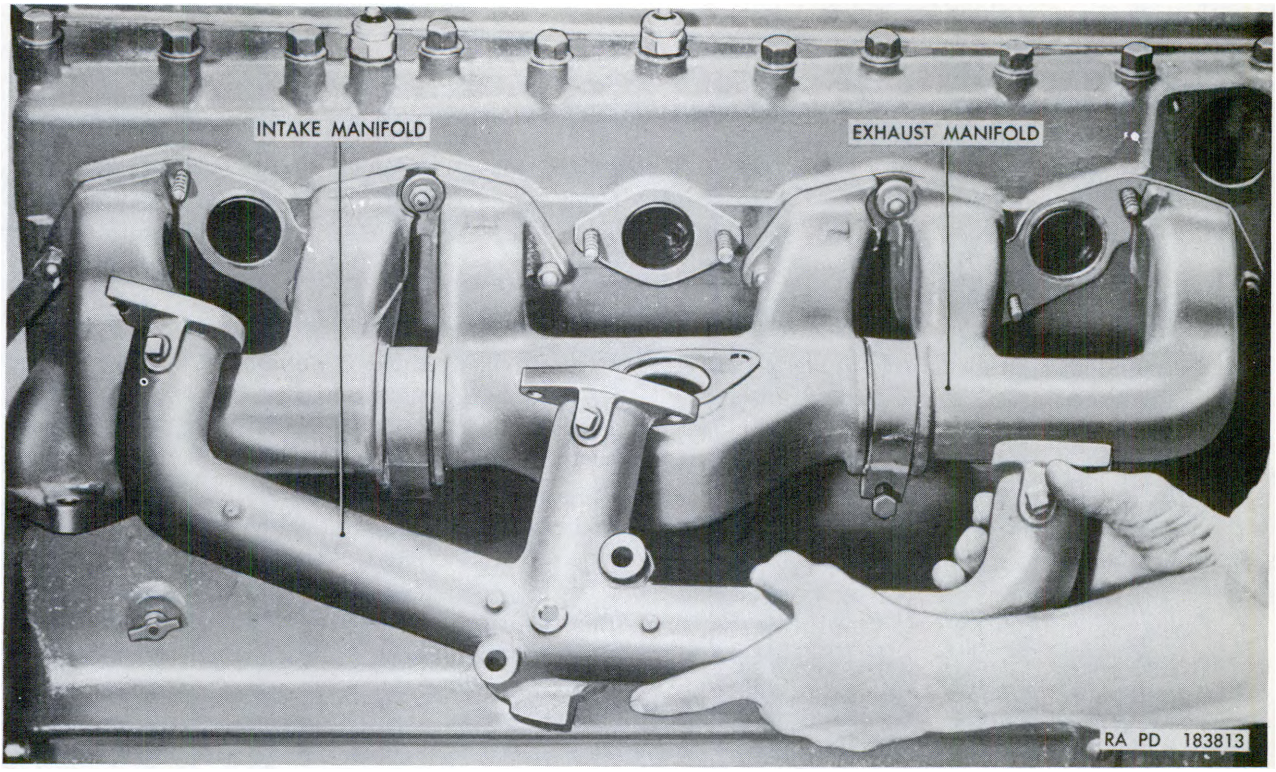

INTAKE MANIFOLD
EXHAUST MANIFOLD
RA PD 183813

Figure 68. Intake and exhaust manifolds.

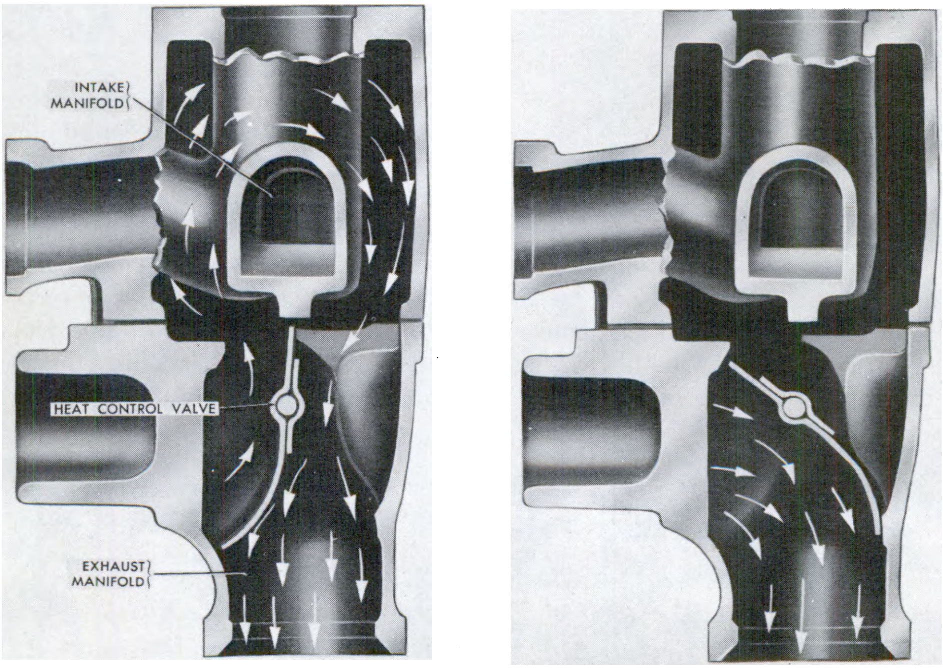

INTAKE MANIFOLD
HEAT CONTROL VALVE
EXHAUST MANIFOLD
RA PD 354324

Figure 69. Operation of intake manifold hot spot.

into the tail pipe and do not circulate around the intake manifold. No extra heating of the incoming fuel-air mixture is needed. On some applications, the heat-control valve is adjusted by hand and does not have a thermostat. On these applications, the valve is set to OFF, INTERMEDIATE, or ON, according to the weather and operating conditions.

55. Intake Pipes (Induction Tube), Radial Engine

In radial engines, individual intake pipes, or induction tubes (fig. 28) connect the diffuser section to the intake ports of the cylinders and are constructed of a thin, light alloy-steel tubing. In figure 70, it will be noted that the intake pipe cylinder end is a symmetrical curve to provide a minimum of restriction to the flow of the incoming fuel-air mixture. The lower ends of the intake pipes are inserted into the tangential ports of the diffuser section and are made gastight by rubber rings or seals and gland locking nuts (fig. 28). This arrangement permits the intake pipe to move with the elongation and contraction of the cylinder. It prevents any distortion of the pipe. The intake pipes also function as vaporization chambers, and any fuel remaining in the liquid state vaporizes either in the pipes or the hot cylinders.

56. Exhaust Manifold

The exhaust manifold (fig. 68) carries waste products of combustion from the cylinders. This must be accomplished with as little back pressure as possible. Exhaust manifolds may be single iron castings or may be cast in sections. They should have smooth interior surfaces and no abrupt changes in size. The shape of the exhaust manifold has an appreciable effect on the scavenging action of the engine, and for best results no more than three cylinders should be connected to one manifold. On a radial engine, the exhaust manifold (fig. 71) is in different form although serving the same purpose. The exhaust manifold usually is in two segments installed on the rear of the engine. Tangential pipes lead from the exhaust ports of each cylinder to two main pipes which provide outlets, one on each side of the engine.

57. Muffler

The muffler reduces the pressure of exhaust gases and discharges them to the atmosphere with a minimum of noise. It is used near or at the end of the exhaust pipe (fig. 72). A typical muffler (fig. 73) has several concentric chambers with openings between them. The gas enters the inner chamber and expands as it works its way through a series of holes into the other chambers and finally to the atmosphere. Mufflers must be designed to avoid back pressure which would reduce engine power and speed and cause engine overheating. The most common cause of back pressure is deposits of oil and carbon which clog muffler passages.

58. Distribution Impeller

a. On engines with a large number of cylinders, the uniform distribution of the fuel-in mixture becomes a greater problem. The fuel, as atomized into the air stream which flows in the induction system, consists of small globules or droplets. Partial vaporization takes place at this time and the air temperature falls due to the absorption of the heat of vaporization. The final vaporization takes place when the mixture enters the cylinders, where higher temperatures prevail. The air entering the carburetor drops in temperature because of the cooling effect of the partial vaporization of the fuel at the carburetor dis-

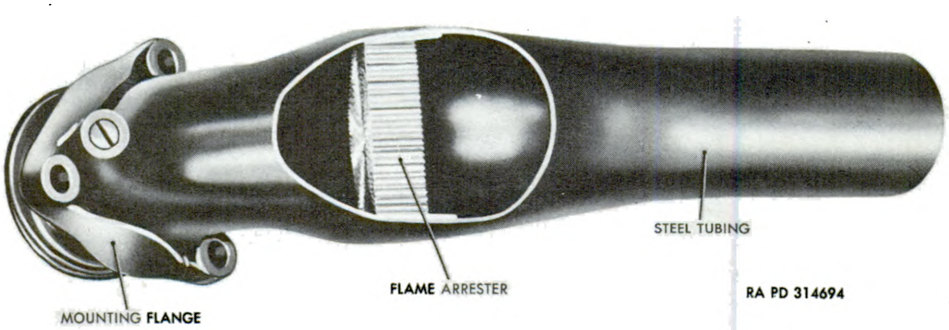


Figure 70. Radial engine intake pipe.

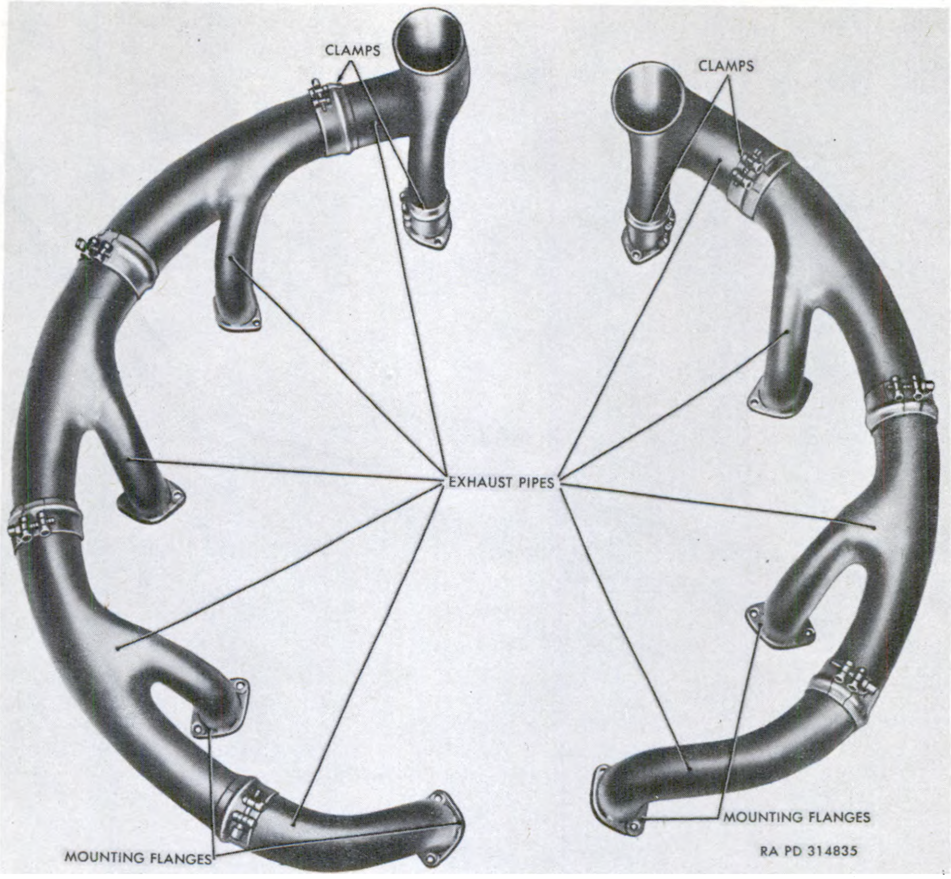


Figure 71. Radial engine exhaust manifolds.

charge nozzle and the cooling effect produced by the venturi action (par. 445). The problem becomes one of uniformly breaking up and distributing the fuel, remaining in globular form, to the various cylinders, regardless of variation of piping arrangement and cylinder pressures.

b. The impeller unit (fig. 74) of a radial engine is located between the carburetor and the intake pipes or induction tubes and is built as an integral part of the engine. It is turned at high speed (usually 10 to 1, relative to the crankshaft speed) by a gear train driven by the crankshaft gear. The fuel-air mixture enters the impeller at the center and is thrown outward at high velocity by centrifugal force into the diffuser chamber, a narrow, annular (ring-shaped) passage surrounding the impeller and formed by the space between the accessory, or rear, crankcase section and the diffuser section of the crankcase assembly. From the diffuser chamber, the mixture flows into the distribution chamber or manifold ring, which extends around the entire diffuser assembly.

c. The impeller is profiled out of a solid Duralumin forging, and the vanes are curved in such a manner as to strike the mixture at an angle in order to reduce shock load. It usually is fitted with a steel hub containing splines which fit on the splined impeller shaft. Due to the temperature drop accompanying vaporization, the remaining fuel is in a globular form when it strikes the impeller blades. The centrifugal force of the impeller will break it up considerably, permitting the fuel to come in contact with air more easily; the heat rise due to partial compression of the mixture in the diffuser chamber also aids vaporization. The impeller, therefore, puts the mixture in a vaporized form and increases its distribution to the cylinders.

d. The distribution impeller is commonly referred to as a supercharger, although the principal purpose of a supercharger is to put enough pressure on the fuel-air mixture so that the engine will be supplied with a greater weight of fuel-air mixture than would be induced normally

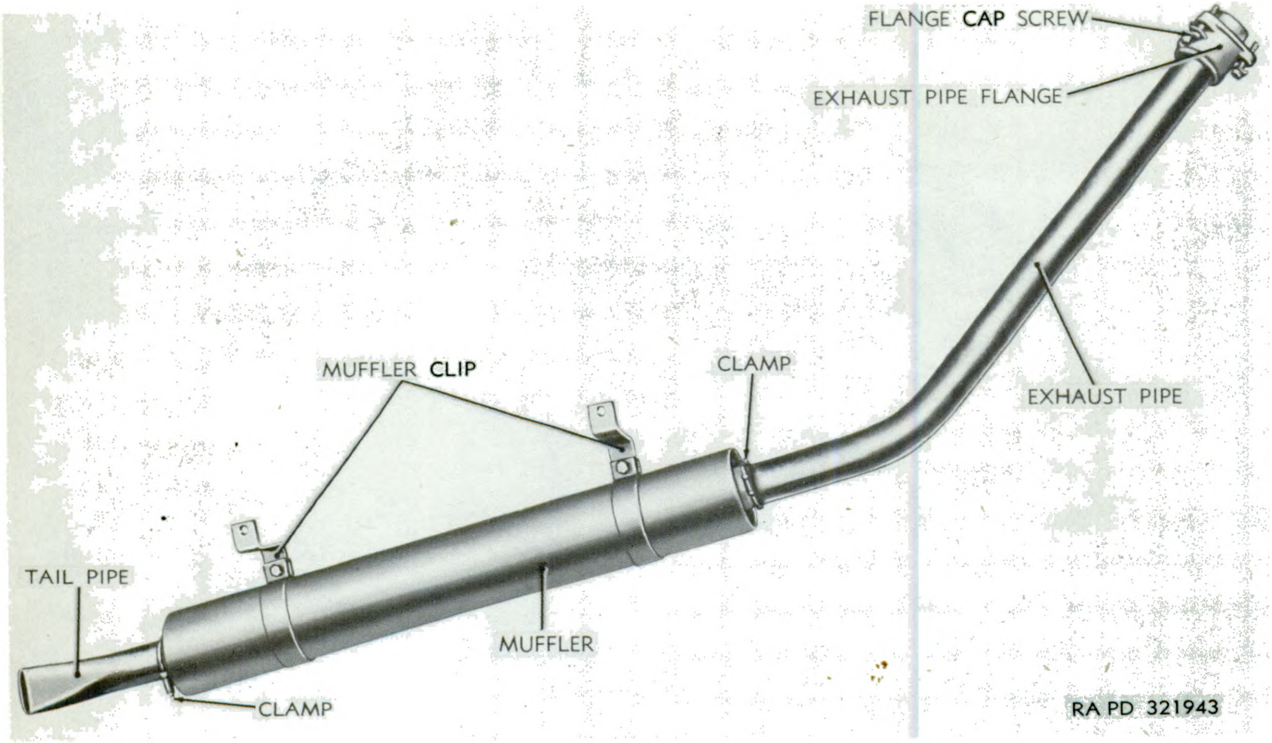

FLANGE CAP SCREW
EXHAUST PIPE FLANGE
MUFFLER CLIP
CLAMP
EXHAUST PIPE
TAIL PIPE
MUFFLER
CLAMP
RA PD 321943

Figure 72. Muffler and exhaust pipe.

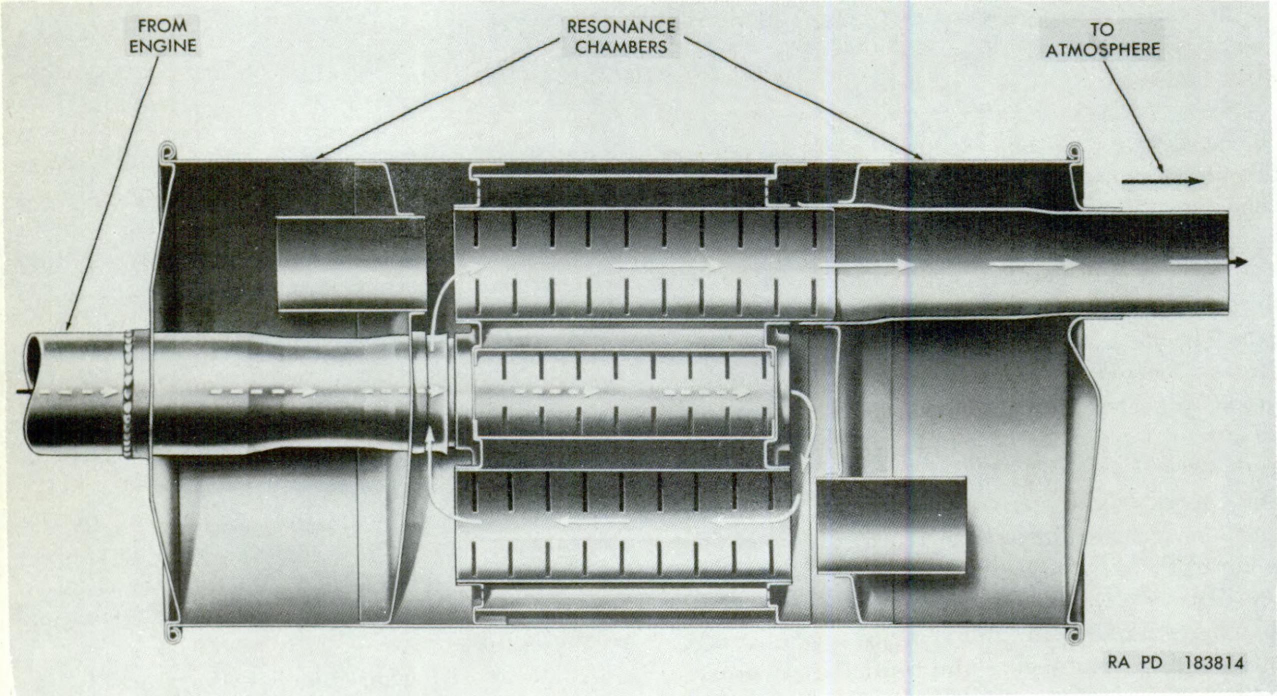

FROM ENGINE
RESONANCE CHAMBERS
TO ATMOSPHERE
RA PD 183814

Figure 73. Internal construction of a muffler.

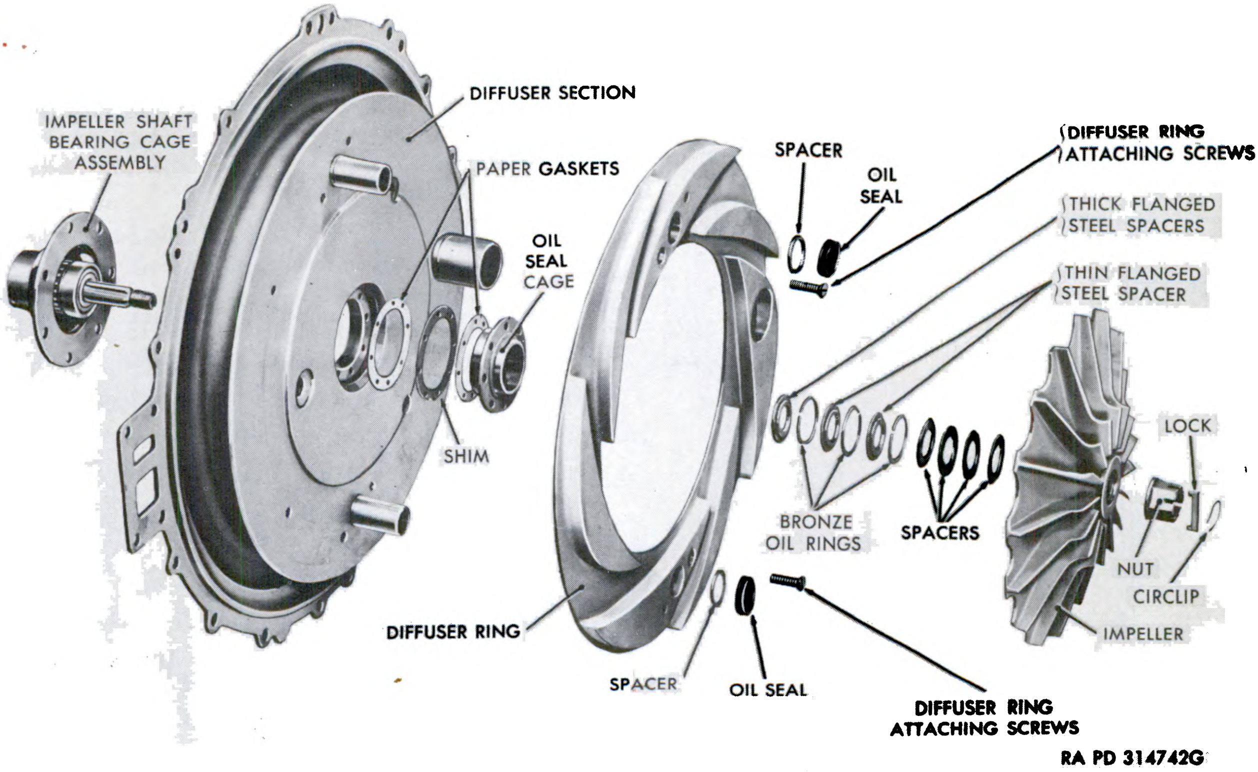

IMPELLER SHAFT BEARING CAGE ASSEMBLY
DIFFUSER SECTION
PAPER GASKETS
OIL SEAL CAGE
SHIM
DIFFUSER RING
SPACER
OIL SEAL
DIFFUSER RING ATTACHING SCREWS
THICK FLANGED STEEL SPACERS
THIN FLANGED STEEL SPACER
LOCK
BRONZE OIL RINGS
SPACERS
NUT
CIRCLIP
IMPELLER
SPACER
OIL SEAL
DIFFUSER RING ATTACHING SCREWS
RA PD 314742G

Figure 74. Impeller, diffuser ring, and diffuser section.

at the prevailing pressure. This increases the volumetric efficiency and power output of the engine. The distribution impeller does put a slight pressure on the fuel-air mixture, but only at high speeds. Its main job is to aid vaporization and to distribute the fuel-air mixture equally to all cylinders.

59. Carburetor Circuits

Venturi action and the basic principles of carburetion have been discussed in paragraphs 39 through 45. A simplified carburetor is shown in figure 56. For a carburetor to satisfactorily vary the fuel-air ratio for different operating conditions, several controls and circuits must be added to the simplified carburetor. These different circuits are discussed in paragraphs 60 through 70.

60. Throttle

The first and most important control that the carburetor requires is a means of varying the amount of fuel-air mixture that enters the intake manifold. When a maximum amount can enter, the engine cylinders will produce maximum power (for the speed at which it is running). When less than maximum power is required (as when cruising slowly or idling), the engine must be throttled down. This is accomplished by reducing the amount of fuel-air mixture with a throttle valve (fig. 75) in the carburetor. The throttle valve is simply a round disk mounted on a shaft so it can be tilted at various angles in the carburetor throttle valve body. When it is parallel to the air flow, it offers almost no restriction and a full volume of fuel-air mixture can pass into the intake manifold. But when it is tilted away from this position, it reduces the amount of air that can enter and thus the amount of fuel-air mixture that can pass into the intake manifold. Engine power is therefore cut down. The throttle valve is connected by linkage to the throttle pedal (accelerator) in the driving compartment. When the pedal is depressed, the throttle valve is opened, which means it is tilted in the throttle valve body so as to offer less restriction and permit more fuel-air mixture to pass through.

61. Float Circuit

a. The fuel level in the carburetor bowl must be maintained at a constant level during engine operation. If the level is too high, fuel will feed too freely out of the nozzle and the mixture will be

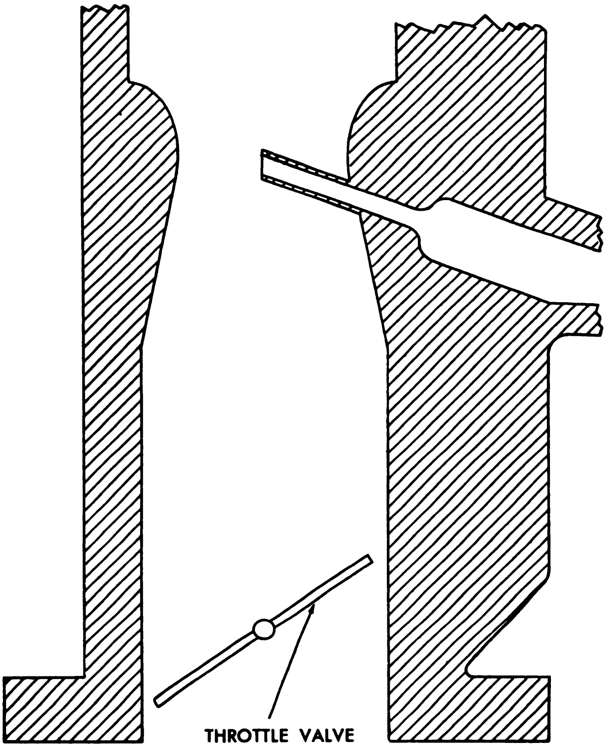


Figure 75. Simple carburetor with throttle valve.

too rich, high fuel consumption will result and the engine may suffer from formation of large amounts of carbon in the cylinders. On the other hand, if the fuel level is too low, insufficient fuel will feed from the nozzle and the mixture will be too lean for good engine performance. To maintain the correct level, a float circuit is used. Essentially, this circuit consists of a float pivoted at one side of the bowl and so arranged as to operate a needle valve (fig. 76). As explained in paragraph 52, the fuel pump delivers fuel under pressure to the bowl. When fuel is delivered faster than it is used, the bowl tends to fill up. This causes the float to rise and, thereby, move the needle valve into its seat. This action shuts off the flow of fuel to the bowl. When the fuel level falls, the float falls also and this allows the needle valve to move out of its seat so as to permit the entrance of more fuel. In actual operation, the float and needle valve maintain a position that permits the fuel coming in to just balance the fuel going out of the bowl.

b. The vent at the top of the bowl (fig. 76) may be opened to the atmosphere or it may be vented into the carburetor air horn. In the latter case, a dirty air cleaner will have little effect on mixture richness. However, if the vent is to the atmosphere and if the air cleaner is dirty, the mixture may become overly rich. The reason for this is that dirt in the air cleaner acts as a restriction and thereby increases the vacuum in the air horn and at the fuel nozzle. This causes a heavier discharge of fuel and greater mixture richness. If the vent is to the air horn, the effect of the dirty cleaner will be the same on the vent as on the fuel nozzle and there will be no increase of richness due to the dirty cleaner.

62. Low-Speed Circuit

a. When the throttle is almost closed, there will be very little air passing through the venturi. Therefore, there will be very little vacuum at the venturi and the fuel nozzle will not discharge any appreciable amount of fuel. Without some additional circuit to assure fuel delivery with a closed throttle, the engine would stop. The circuit that takes care of fuel delivery during closed or nearly closed throttle is called the *idle- and low-speed circuit* (fig. 77). Actually, in some respects, this is really two circuits, an idle circuit and a low-speed circuit.

b. When the throttle is closed, there is a relatively high vacuum in the intake manifold and below the throttle. The idle circuit has a discharge port, or hole, that is just below the throttle valve when it is closed. With a closed throttle, there is a vacuum in the intake manifold and, therefore, at the discharge hole. Atmospheric pressure in the float bowl will force fuel from the float bowl through the idle circuit and out the discharge hole. An adjustable needle valve is arranged to permit more or less fuel to discharge from the hole; this makes it pos-

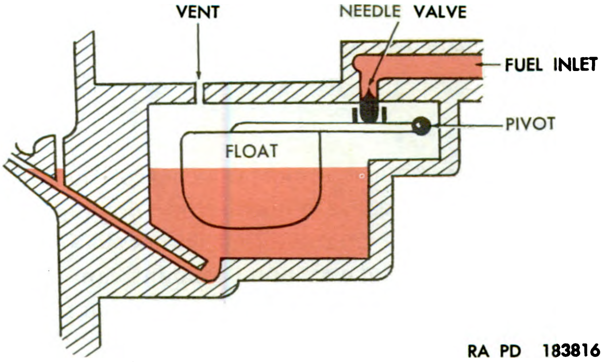


Figure 76. A typical float circuit.

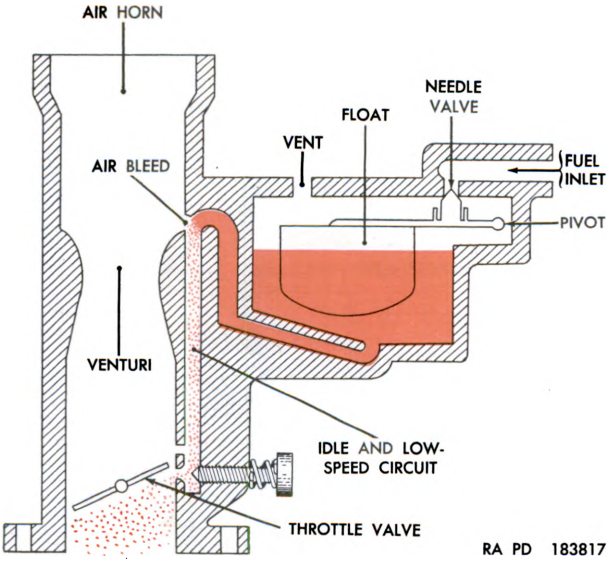


Figure 77. A typical idle- and low-speed circuit.

sible to adjust the idling mixture richness by allowing more or less fuel to discharge during idle.

c. An air bleed is arranged to allow air to bleed into the idle circuit when it is operating. This air mixes with the fuel and partly atomizes it before it discharges from the hole into the air horn. Some such assistance is needed because air movement through the horn is much slower and, therefore, there is less tendency for atomization to take place at the hole during idle. The air bleed also helps to produce fuel flow when pressure differences (between upper and lower portion of the air horn) are low; the mixture flows easier than liquid fuel alone.

d. When the throttle is opened a little, the air flow is still too restricted for the venturi to discharge fuel. Yet more air is flowing and, consequently, more fuel must discharge. The idle-circuit discharge hole alone cannot supply this additional fuel. To supply the additional fuel needed for this low-speed operation, an additional hole (low-speed discharge hole or port) is included in the idle circuit. This hole is so placed that it is slightly above the edge of the throttle valve when it is closed, but slightly *below* the edge of the throttle valve when it is opened a small amount. In this latter position, intake manifold vacuum can act on the low-speed hole and therefore supply additional fuel from the bowl through the circuit. The same circuit is used by both the idle- and the low-speed holes. The low-speed hole simply permits more fuel to discharge into the throttle-valve body as the throttle is swung away from the fully closed position.

63. High-Speed Circuit

a. The high-speed circuit, described in paragraph 44, consists essentially of the main nozzle, which is centered in the venturi. The carburetor normally contains a multiple venturi; that is, several venturi, one inside another. For example, three venturi are shown in figure 79. When the throttle is opened sufficiently, the air passing through creates a pressure difference (par. 44) which causes a discharge of fuel from the nozzle. Throughout the intermediate and high-speed range, this discharge increases with the volume of air passing through so that a fairly uniform fuel-air mixture ratio is maintained. Assisting in maintaining this fairly constant ratio is an air bleed which is incorporated in the nozzle. With increased air speed through the venturi, increased air bleeding into the main nozzle takes place, preventing overrichness. Note the air bleeds in figures 78 and 79.

b. The high-speed and low-speed circuits overlap. As the throttle is moved from closed to opened position, for example, the idle low-speed and high-speed circuits successively take over the main job of supplying fuel. With a closed throttle, the idle discharge hole alone supplies fuel. As the throttle is opened so its edge moves past the low-speed hole, the low-speed hole begins to discharge fuel to meet the added fuel requirements of the engine as engine speed increases. As the throttle opens still wider, the additional and faster-moving air through the air horn begins to produce fuel discharge from the main nozzle. As the main nozzle takes over, the low-speed discharge hole is closed.

c. The carburetor is so designed that the fuel-air ratio of the mixture supplied with an open throttle provides economical operation. This ratio is somewhere around 15:1, by weight (par. 47*a*). If the mixture is enriched to around 11:1 or 12:1, the engine will produce greater power even though it will not run quite as economically. To increase engine power for high-speed or heavy-load operation (as when pulling up a hill), and still maintain reasonable economy, an additional circuit is included in the carburetor which enriches the mixture with a wide-open throttle. Several varieties of full-power circuits are described in (1), (2), and (3) below.

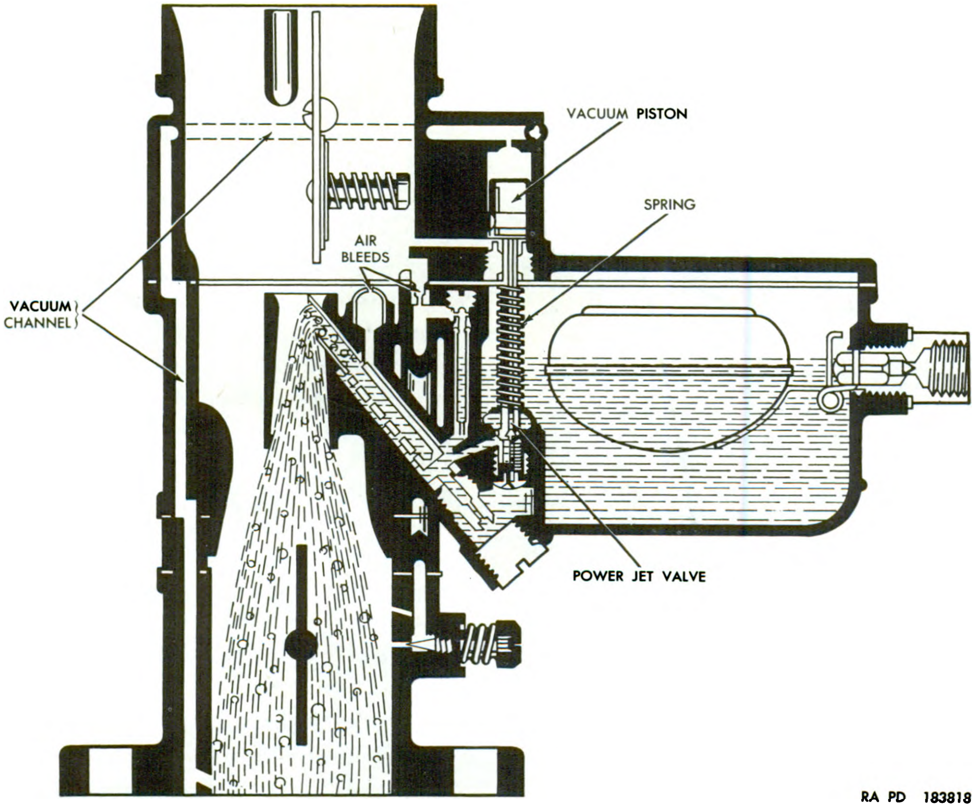


Figure 78. Power jet.

(1) *Power jet.* In some carburetors, a power jet provides the additional fuel necessary for maximum power at wide-open throttle. The power-jet valve (fig. 78), controlled by a vacuum-actuated piston assembly, operates in accordance with the throttle opening. With the throttle closed, a high manifold vacuum is present, and the vacuum-controlled piston assembly is moved by atmospheric pressure in the float chamber to the top of its cylinder against the tension of a spring, closing the valve. When the throttle is opened to a point where additional fuel is required, the manifold vacuum has decreased sufficiently so that the spring on the piston assembly moves the piston down, thereby opening the power jet to feed additional fuel into the high-speed circuit. The jet valve is sometimes referred to as the economizer valve since its operation provides full-power operation where needed and more economical operation at other times.

(2) *Metering rod.* Instead of using a power jet, some carburetors accomplish the same result by employing a metering rod (fig. 79) which varies the size of the high-speed jet openings. Fuel from the float bowl is metered to the high-speed circuit through the calibrated orifice provided by the high-speed jet and the metering rod within it. From this point, the fuel is conducted to the nozzle extending into the venturi. As the throttle valve is opened, its linkage raises the metering rod in the jet. The rod has several steps, or tapers, machined on the lower end and, as it is raised in the jet, it makes the effective size of the fuel orifice greater, permitting more fuel to flow through the circuit to meet the load demand imposed upon the engine. At the wide-open throttle position, the smallest step of the metering rod is in the circular opening of the jet, permitting the maximum amount of fuel to flow through the circuit to meet the requirements of maximum power. The metering rod position

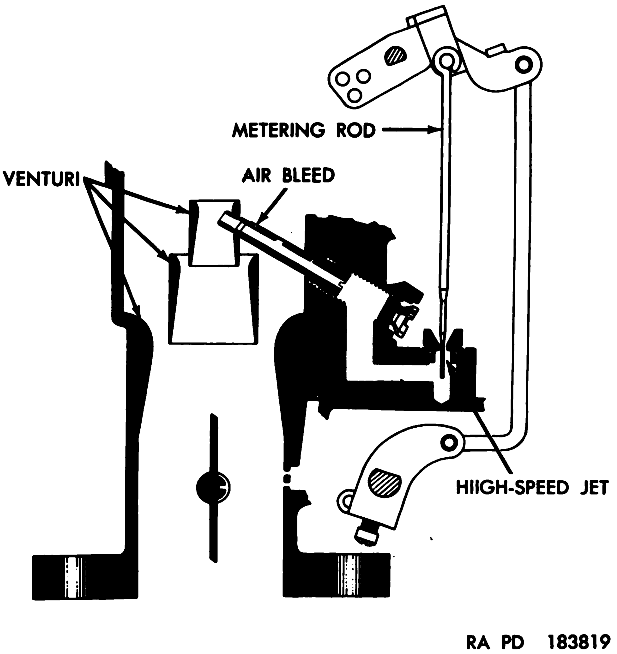


Figure 79. Metering rod circuit.

must be synchronized with every throttle valve position so that the proper ratio of air and gasoline is delivered to the engine for all speeds and driving conditions.

(3) *Vacuum step-up.* The vacuum step-up (fig. 80) operates much like the power jet. It consists of a step-up piston which is fastened to a step-up rod. When high vacuum develops in the intake manifold, as it does under part-throttle operation, atmospheric pressure holds the step-up piston down against its spring pressure so that the step-up rod is held down in the step-up jet, thus, closing off the jet. With wide-open throttle, there will be a low vacuum in the intake manifold and the difference in pressure above and below the piston is small. Consequently, the piston is moved up by its spring pressure and the rod is raised out of the jet. Additional fuel for full-power operation is supplied.

64. Accelerating Pump Circuit

The accelerating pump circuit controls a small amount of fuel that is momentarily discharged into the air stream when the throttle is opened quickly. This extra amount of fuel is necessary to insure instantaneous response from the engine on acceleration. When the throttle is suddenly opened, air rushes through both the carburetor and the intake manifold. The air is lighter than the liquid fuel and gets into motion quicker, so it reaches the manifold before the fuel charge supplied by the high-speed system. This results in a momentarily lean mixture. To counteract this condition, additional fuel must be supplied; this is accomplished by the accelerating pump circuit.

a. The accelerating pump circuit consists of a pump cylinder; a plunger mechanically actuated by a lever mounted on the throttle shaft, or vacuum-operated by intake manifold vacuum; an intake check valve located in the bottom of the pump cylinder to control the passage of fuel from the bowl into the pump cylinder; a discharge check valve; and an accelerating jet to meter the amount of fuel used. A typical arrangement with a mechanically actuated plunger is shown in figure 81.

b. When the throttle is opened, the pump plunger moves downward in its cylinder. If the plunger is mechanically operated, the downward movement will be brought about by direct linkage with the throttle. If it is vacuum-actuated, a sudden throttle opening will cause the manifold vacuum to drop, allowing the accelerating pump spring to force the pump plunger down in the cylinder. In either case, the subsequent action of the accelerating-pump circuit is the same. The downward travel of the plunger forces fuel past the discharge check valve to the accelerating jet,

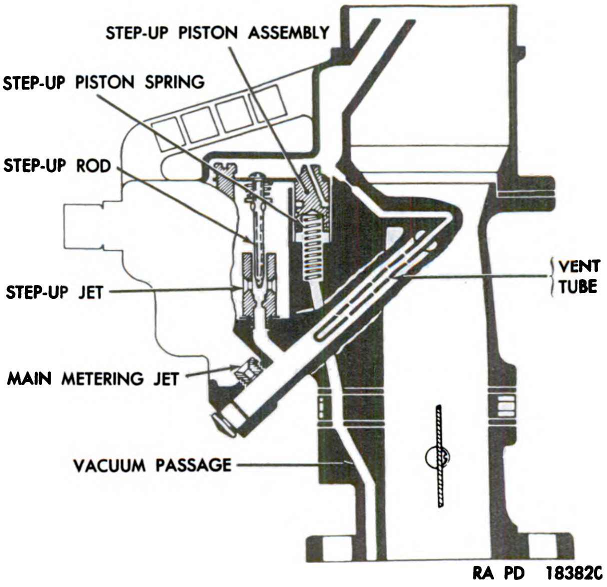


Figure 80. Vacuum step-up circuit.

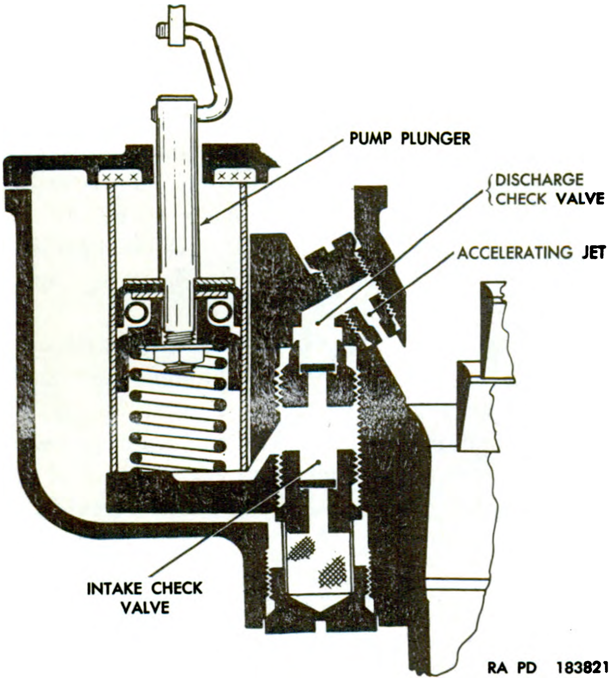


Figure 81. Accelerator circuit.

which meters the rate at which it is discharged into the air stream. Fuel is supplied to the pump cylinder through the intake check valve at the bottom. The level of fuel in the pump cylinder when the plunger is held up to the top of its stroke is approximately equal to the level in the fuel bowl. The intake check valve in the bottom of the cylinder permits a supply of fuel to reach the cylinder but closes on the down stroke of the plunger, preventing the fuel in the cylinder from being pushed back into the bowl. The accelerating-pump discharge is only needed momentarily when the throttle is opened suddenly. To prevent the accelerating jet from flowing at constant throttle openings, some models have an air-vent check valve placed between the accelerating jet and pump cylinder above the fuel level. At steady part-throttle positions, when the pump plunger is inoperative, no pressure exists on the fuel in the pump cylinder. Under this condition, the air-vent check valve will be open and the air will enter the passage connecting the pump cylinder and accelerating jet, preventing fuel from flowing through the jet. The pressure on the fuel, created by the down stroke of the pump plunger, causes the air-vent check valve to close against its seat to prevent the fuel from being discharged back into the bowl through the air-vent passage. On some carburetors, the area above the plunger is connected to the intake manifold so that the accelerating pump does not work while the engine is not running. Under these conditions, the pressure in the intake manifold is near atmospheric and holds the pump plunger down.

c. Successful operation of the accelerating pump depends on a delayed action which provides a continual stream of fuel from the pump jet after the throttle has ceased moving. This is to take care of the fuel demands of the engine in the interval that exists between the time the throttle is opened and the time the high-speed nozzle begins to discharge fuel.

(1) Some carburetors achieve this action by means of the *dry pump*. A pocket of air is maintained in the plunger cup between the plunger and the fuel. When the plunger is pushed down, it compresses this air. The compressed air, in turn, forces the fuel from the pump cylinder. At the end of the plunger stroke, the compressed air expands, providing the necessary force to continue the fuel discharge. If some of the air below the plunger is absorbed by the gasoline, a small amount of air escapes downward past the plunger, replenishing the supply of air necessary for delayed action in the pump cylinder. A carburetor employing a dry pump does not require an air vent to prevent the accelerating jet from flowing at constant throttle openings. The air remaining in the cylinder is below atmospheric pressure and does not exert enough force to cause fuel to flow. Some models use a pump-connector-link spring instead of the regulation pump-connector link. The spring has a double purpose, one of which is to assist in the delayed action of the pump discharge. When the throttle is opened suddenly, the plunger is driven down in the cylinder but the spring is also slightly compressed. As the spring expands to its normal position, it aids in pushing the plunger against the air pocket and assists in the delayed delivery of fuel through the pump jet. The spring also will absorb any strain on the linkage if the pump jet becomes obstructed.

(2) Another type of accelerating pump is called a *wet pump*, and functions with-

out any cushion of air underneath the pump plunger. For its delayed action, this type of pump circuit depends upon the pump spring. Its expansion continues the discharge of fuel for a brief period after the sudden opening of the throttle. This operation is effected by a different linkage arrangement. As the throttle is closed, the pump-operating link raises the plunger in the pump cylinder, compressing the pump spring. When the throttle is opened, the linkage permits the spring to drive the plunger downward.

65. Dual Carburetors

All the carburetors discussed in paragraph 64 have single barrels. Many carburetors, particularly those for engines with more than six cylinders, have two barrels. Each barrel is a complete carburetor, with its own idle, low-speed, and high-speed circuits, and an accelerator-pump discharge jet. There is a separate throttle valve for each barrel, but both are mounted on a single throttle shaft so that they open and close together. The purpose of the two barrels is to split the responsibility of fuel-air-mixture delivery to the various cylinders between two semi-independent carburetors. For instance, in an 8-cylinder, in-line engine, one barrel might take care of cylinders nos. 1, 2, 7, and 8 while the other barrel would take care of cylinders nos. 3, 4, 5, and 6. With such an arrangement, there would be two intake manifolds, one feeding one group of cylinders from one barrel of the carburetor and the other feeding the other group from the other barrel.

66. Choke Circuit

a. When the engine is cold, the gasoline vapors tend to condense into large drops on their way to the cylinders. Because all the gasoline supplied to the cylinders will not vaporize, it becomes necessary to supply a richer mixture to have enough vapor to assure combustion. This is accomplished by the choke circuit, which is a choke valve plate placed in the carburetor throat above the venturi.

b. When a driver operates the choke, the choke valve tilts in the air horn to reduce the amount of air entering the throat, giving a very rich mixture. Only the volatile parts of the gasoline will vaporize at cold temperatures; therefore, a rich mixture is necessary. It provides enough ignitable vapor to start the engine. However, if the choke valve is in the full-choke position, it is completely closed, shutting off the supply of air. Consequently, there is not enough air entering the throat to ignite the gasoline. The necessary air is admitted in manual chokes by either one of two semiautomatic features.

(1) In one design, the choke valve incorporates a springloaded poppet valve (fig. 82). The poppet is held in the closed po-

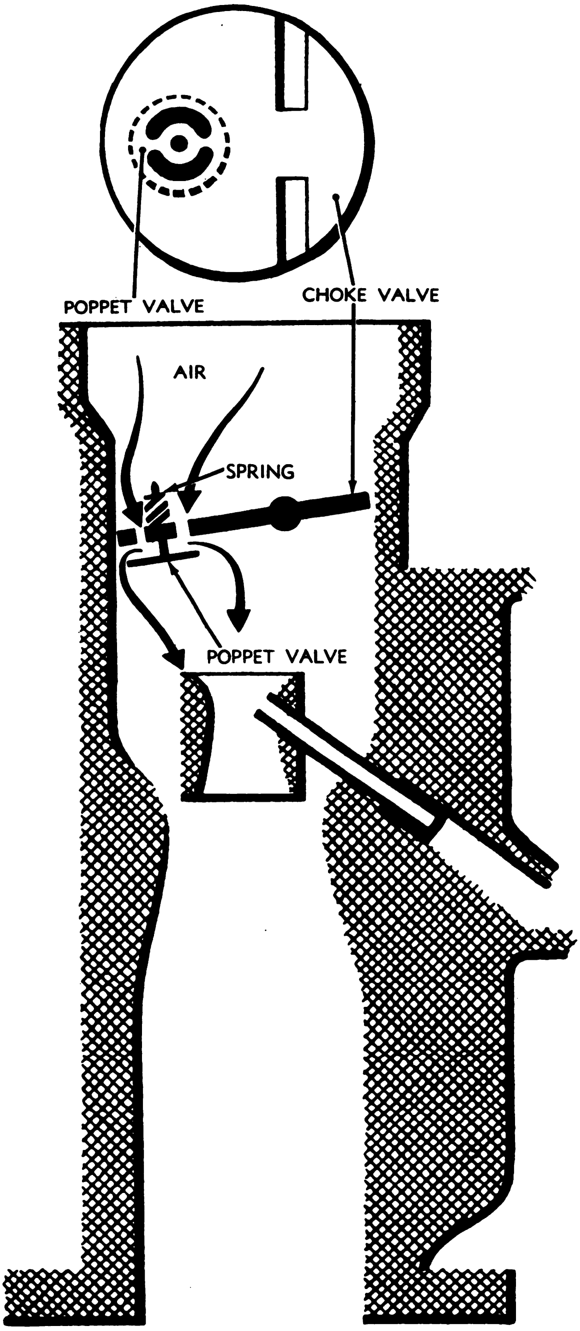


Figure 82. Spring-loaded poppet valve in choke valve.

sition by a weak spring. As soon as the engine turns over, there is sufficient pressure differential to open the valve, allowing air to flow.

(2) In the other design, the valve is off-center (fig. 83) and operates through a coiled spring on the end of the choke shaft (fig. 84). In the full-choke position, the spring holds the choke valve in the closed position. As soon as the engine turns over, an increased pressure differential overcomes the spring tension and opens the choke valve part way, admitting air to avoid overchoking or flooding the engine. As the engine warms up, the choke valve is gradually advanced to the wide-open position by the operator to supply the leaner mixture required for a hot engine.

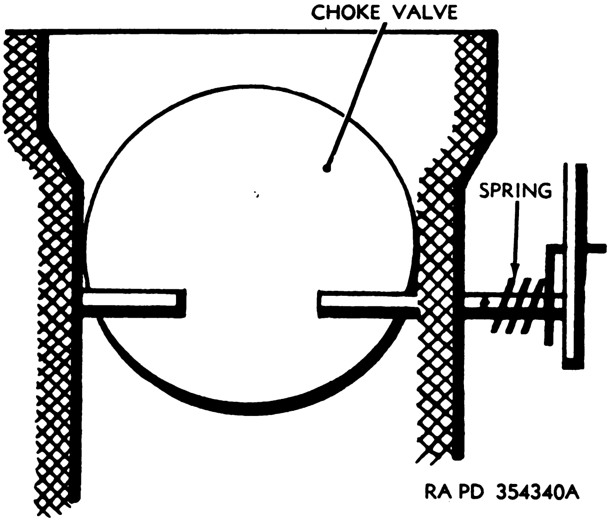

CHOKE VALVE
SPRING
RA PD 354340A

Figure 83. Off-center choke valve.

67. Automatic Choke

a. The automatic choke (figs. 84 and 85) replaces the conventional manual choke. It not only controls the fuel-air ratio for quick starting at any temperature, but also provides for the proper amount of choking to enrich the fuel-air mixture for all conditions of engine operation during the warm-up period. The automatic choke is built into the carburetor. It consists of a thermostatic (bimetal) spring and a vacuum piston which opposes the action of the spring. The spring is connected to the choke valve in such a manner as to close the valve when the spring is cold. The vacuum piston tends to open

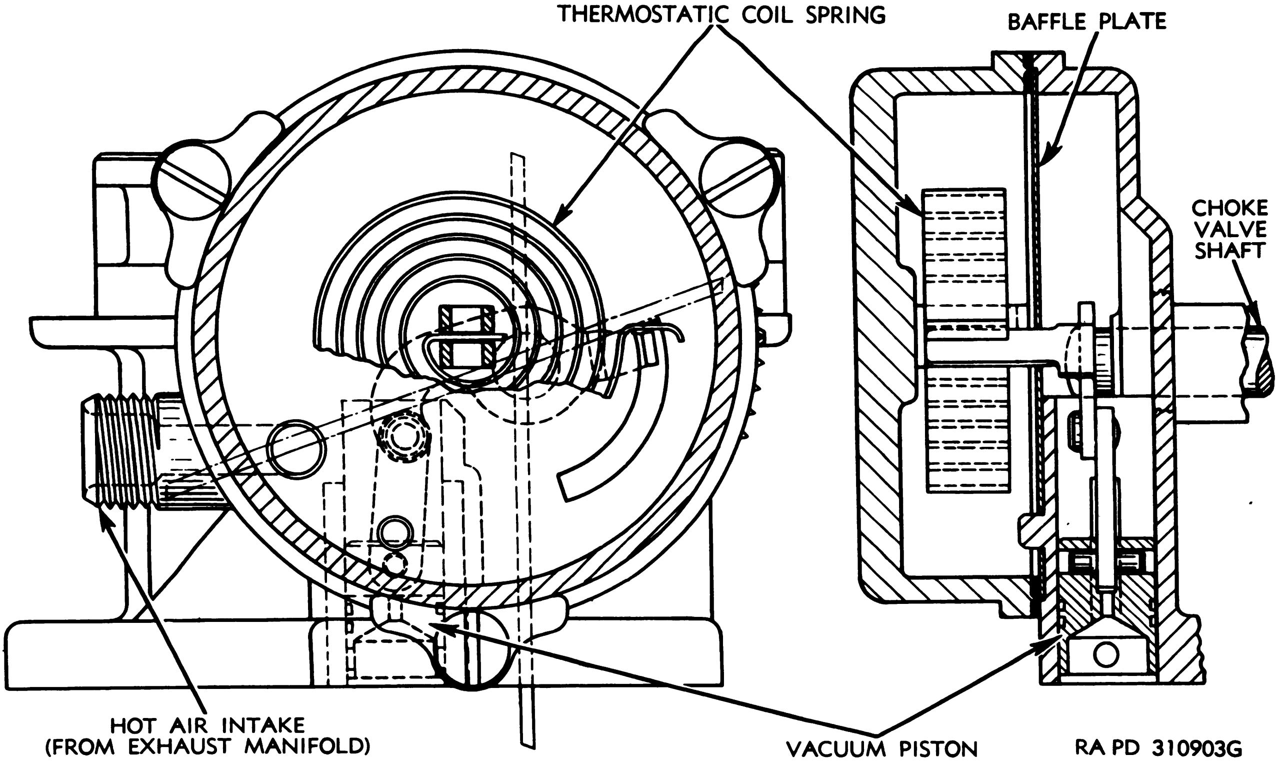

THERMOSTATIC COIL SPRING
BAFFLE PLATE
CHOKE VALVE SHAFT
HOT AIR INTAKE (FROM EXHAUST MANIFOLD)
VACUUM PISTON
RA PD 310903G

Figure 84. Automatic choke.

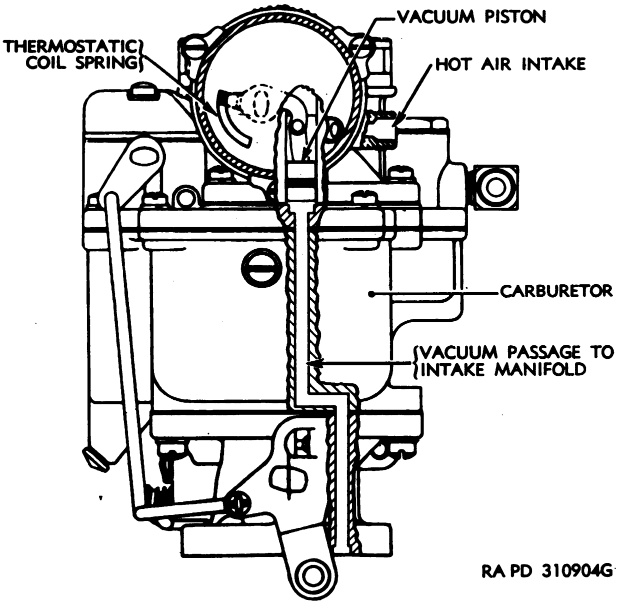


Figure 85. Automatic choke.

the choke valve when the engine manifold vacuum is high. The choke valve is mounted off-center on the choke shaft so that any increase in air velocity through the air horn will tend to open the valve.

b. The operation of the automatic choke is dependent on three factors: heat, intake manifold vacuum, and the velocity of air passing through the air horn. When the engine is cold, the thermostatic spring holds the choke valve closed. When the engine is started, the low pressure (high vacuum) below the throttle valve permits atmospheric pressure to move the piston down and partially open the valve against the tension of the thermostatic spring. Under varying load conditions during warmup, the position of the choke valve will be changed by the operation of the vacuum piston working against the thermostatic spring, and the air velocity in the air horn. Hot air from the exhaust manifold is directed to the thermostatic spring so that the spring loses its tension as the engine is heated. This permits the choke to open gradually and, after it reaches full-open position, it is held open by the action of the intake manifold on the piston. When the engine is stopped, the thermostatic spring cools and closes the choke valve. The choke valve is fully closed at a temperature of approximately 70° F.

68. Primer System

a. The primer system (figs. 86 and 87) consists of a hand pump, a pressure line leading to a small distribution chamber, and lines leading to the intake pipes of several of the upper cylinders, the number varying according to the type of radial engine. Fuel is obtained from a small line leading from the main tanks. When the pump plunger is pulled out by a handle, located on the instrument board, fuel is forced through the inlet valve and into the pump barrel (fig. 88). The inward stroke of the plunger stem forces the fuel past the outlet and diaphragm valves, through the pressure line, distribution chamber, and distributor lines, and sprays it into the intake pipes of the upper cylinders. The diaphragm valve is so constructed that comparatively small pressure by the pump will open the valve, allowing fuel to pass for priming. However, if the engine backfires, the extreme pressure required to open the valve from the outlet side prevents the pressure from backing up into the pump, protects the springs of the ball valves, and prevents the balls from being driven down into their seats. The diaphragm valve also prevents fuel from siphoning from the tanks into the engine.

b. The in-line, horizontal-opposed, and V-type engines used in trucks and track-laying vehicles may also have fuel priming systems. In these, a primer pump on the vehicle dash, handy to the driver's seat, is operated to force liquid fuel into various spots along the intake manifold. The primer pump is very similar to the one shown

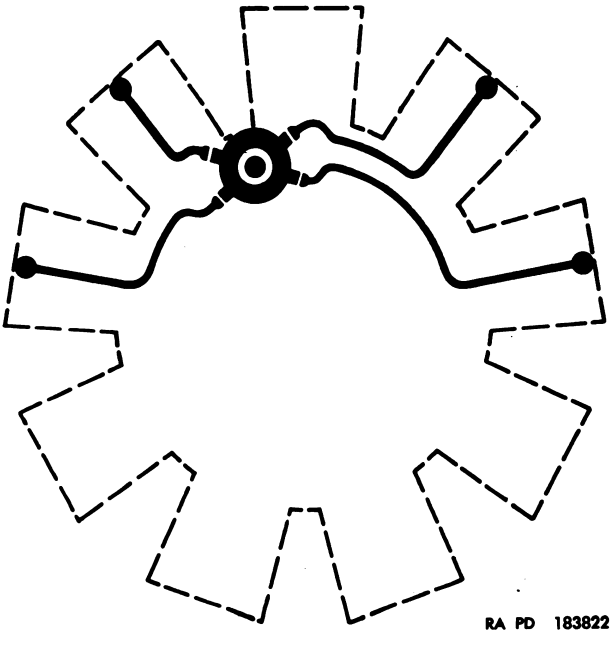


Figure 86. Radial engine primer lines.

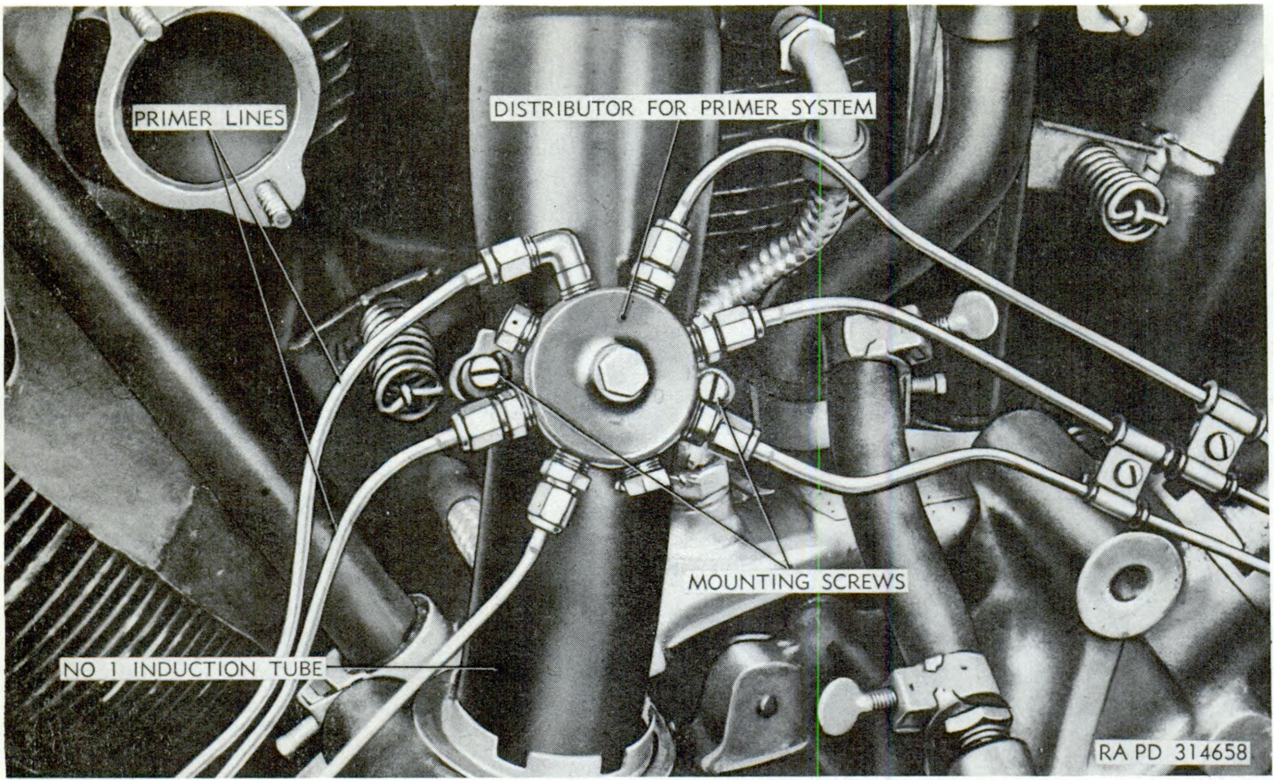


Figure 87. Radial engine primer lines and distributor.

in figure 88 and, in general, works in the same manner.

69. Updraft and Downdraft

Carburetors also are classified as *updraft* or *downdraft*, according to their position with respect to the intake manifold. If the carburetor is below the manifold, it is an updraft type; if placed above the manifold, it is a downdraft type. In early fuel systems, it was necessary that the fuel flow down by gravity to the float chamber, making the updraft carburetor essential because of its low position. However, the introduction of mechanical fuel pumps has eliminated this problem.

70. Degasser

a. The degasser is designed to shut off the fuel supply in the idle circuit when there is a high vacuum in the intake manifold during periods of deceleration. Figure 89 shows a 2-barrel carburetor with a degasser in each barrel. Figure 90 shows a degasser with the idle circuit in operation. Under this condition, the vacuum in the intake manifold is not great enough to cause the degasser to work. The return spring is holding the diaphragm in the degasser in the position shown in figure 90, so that the needle valve is out of the way and fuel can flow. However, with the throttle closed and the vehicle decelerating, the condition shown in figure 91 results. Here, there is increased vacuum in the intake manifold due to the engine running above idling speed with the throttle closed (vehicle driving engine). This increased vacuum is now sufficient so that atmospheric pressure can force the diaphragm back against the return-spring pressure. This causes the fulcrum arm to press against the needle valve and force it to seat, thereby shutting off the flow of fuel to the idle circuit. If the throttle is opened, the vacuum is reduced and the needle valve moves back out of the way as the diaphragm, return spring, and fulcrum arm return to the position shown in figure 90.

b. The degasser is also used to clear the idle circuit and manifold of unburned gases before the engine is turned off. This is done by pressing a button on the dash which energizes the solenoid in the degasser. This causes the plunger to actuate the fulcrum arm and force the needle valve into its seat, thereby shutting off the fuel flow (fig. 92). The engine continues to run until the supply of

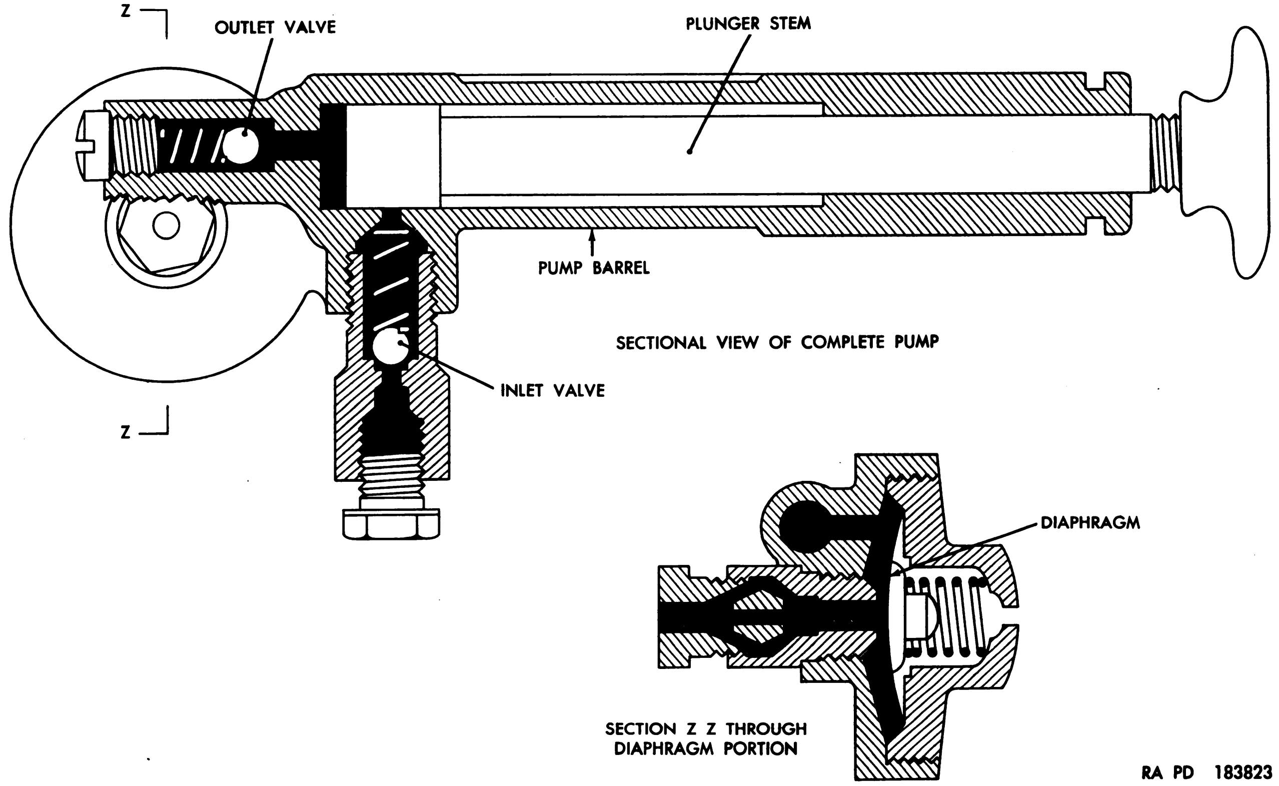


Figure 88. Primer pump.

fuel in the intake manifold is used up and it then dies. The ignition switch should then be turned off. The button used to energize the solenoid must be held in until the engine dies. Then, it can be released to de-energize the solenoid.

71. Injection Systems

On some gasoline engines, an injection fuel system is used. In this system, the carburetor is replaced by an injection pump which meters and delivers the fuel to the intake manifold at the proper time for the intake strokes of the pistons. Figure 93 shows an engine with this type of fuel system. Four fuel lines lead from the fuel injection pump to the intake manifolds at the intake valves of the four cylinders. When the intake stroke of any cylinder starts, the fuel injector pump starts to deliver fuel to that particular cylinder.

72. Governors

Governors are used on automotive vehicles to regulate maximum engine speed and thus prevent excessive wear. Experiments have proved that the rate of wear increases by the square of the engine speed. In higher speed ranges, a change of a few hundred revolutions results in a greatly disproportionate amount of wear. That is why it is advisable to control maximum speeds. Two common types of governors are centrifugal and velocity (or vacuum) governors.

a. Centrifugal. In its basic form, a centrifugal governor is made up of two weighted arms pivoted on a spindle which is connected by suitable linkage to a throttle valve. This is shown schematically in figure 94. A drive shaft, driven from the camshaft or an accessory drive of the engine, causes the rotation of the spindle. The throat in which the valve operates is bolted to the carburetor throat so that any action of the weighted arms on the throttle valve will affect the passage of fuel-air mixture from the carburetor to the cylinders. As the engine operates and the spindle rotates, the weights tend to fly out by centrifugal force but are opposed by the action of the spring against them. A screw at the end of the spring controls the tension with which the spring holds the weights against the spindle. As the centrifugal force of the spindle rotation overcomes the spring tension, the weights will be forced outward and will actuate the throttle valve through the linkage, closing it.

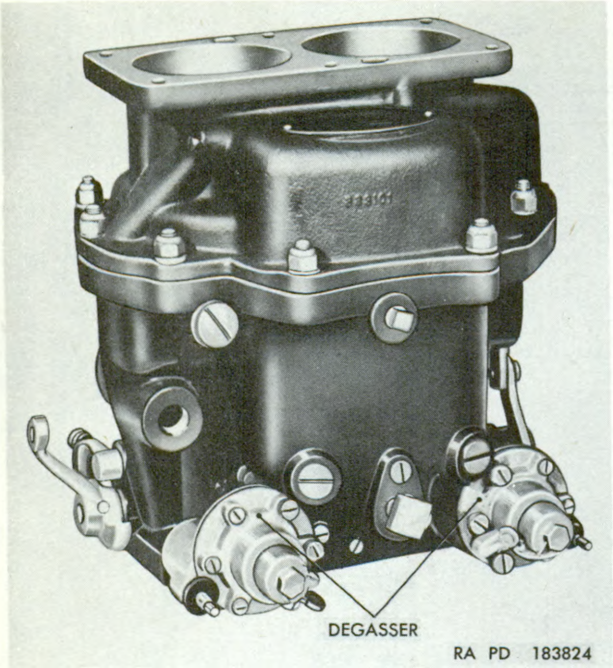

DEGASSER
RA PD 183824

Figure 89. Carburetor with two degassers, one in each barrel.

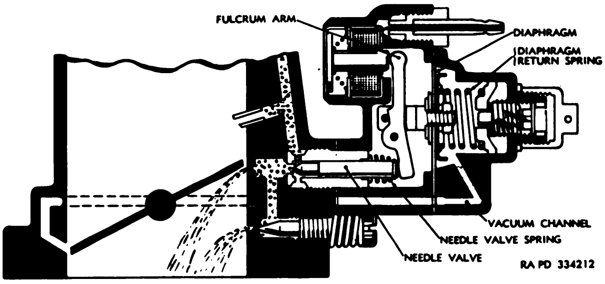

FULCRUM ARM
DIAPHRAGM
DIAPHRAGM RETURN SPRING
VACUUM CHANNEL
NEEDLE VALVE SPRING
NEEDLE VALVE
RA PD 334212

Figure 90. Degasser with idle system in operation.

b. Velocity or Vacuum.

(1) The velocity, or vacuum, governor (fig. 95) is operated by the velocity of the fuel-air mixture and by intake manifold vacuum. On its way to the cylinders, the mixture must pass the throttle valve, which is attached to a shaft mounted in an off-center position in the throat. The throttle valve is set at a slight angle so that the flowing fuel-air mixture tends to close it. The valve is held open by spring tension. Atmospheric pressure, opposing intake manifold vacuum, balances the piston which is connected to the throttle, stabilizes the throttle valve against the pressure of the fuel-air mixture, and prevents it from fluttering. When the force of the fuel-air mixture against the valve overcomes the spring tension, the valve will close and reduce the amount of mixture that enters the cylinders.

(2) Another type of velocity governor is shown in figure 96. This unit has an off-center throttle-valve, as described in (1) above. The throttle-valve shaft has a flywheel mounted on it, and this flywheel is spring-loaded by a mainspring. At wide-open throttle, the throttle-valve position is determined by the velocity of air passing by the valve, and also by the tension of the mainspring. As engine speed increases to the governed value, the increased velocity of the air has enough force on the valve to overcome the tension of the mainspring. The valve is moved toward the closed position. This reduces the amount of fuel-air mixture sufficiently to prevent overspeeding. Governed speed is thereby maintained. At governed speed under light loads, the throttle valve will not be opened as far as under heavy loads. The air striking

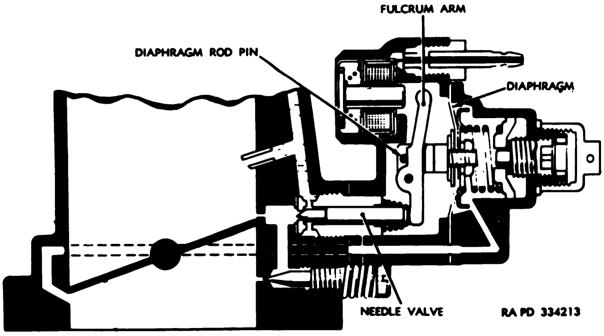

FULCRUM ARM
DIAPHRAGM ROD PIN
DIAPHRAGM
NEEDLE VALVE
RA PD 334213

Figure 91. Degasser with engine decelerating.

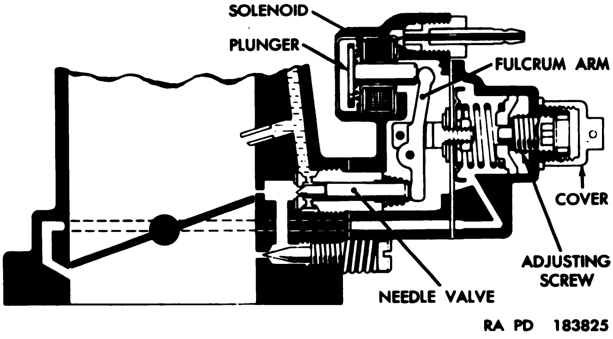

SOLENOID
PLUNGER
FULCRUM ARM
COVER
ADJUSTING SCREW
NEEDLE VALVE
RA PD 183825

Figure 92. Degasser with electric shut-off in operation.

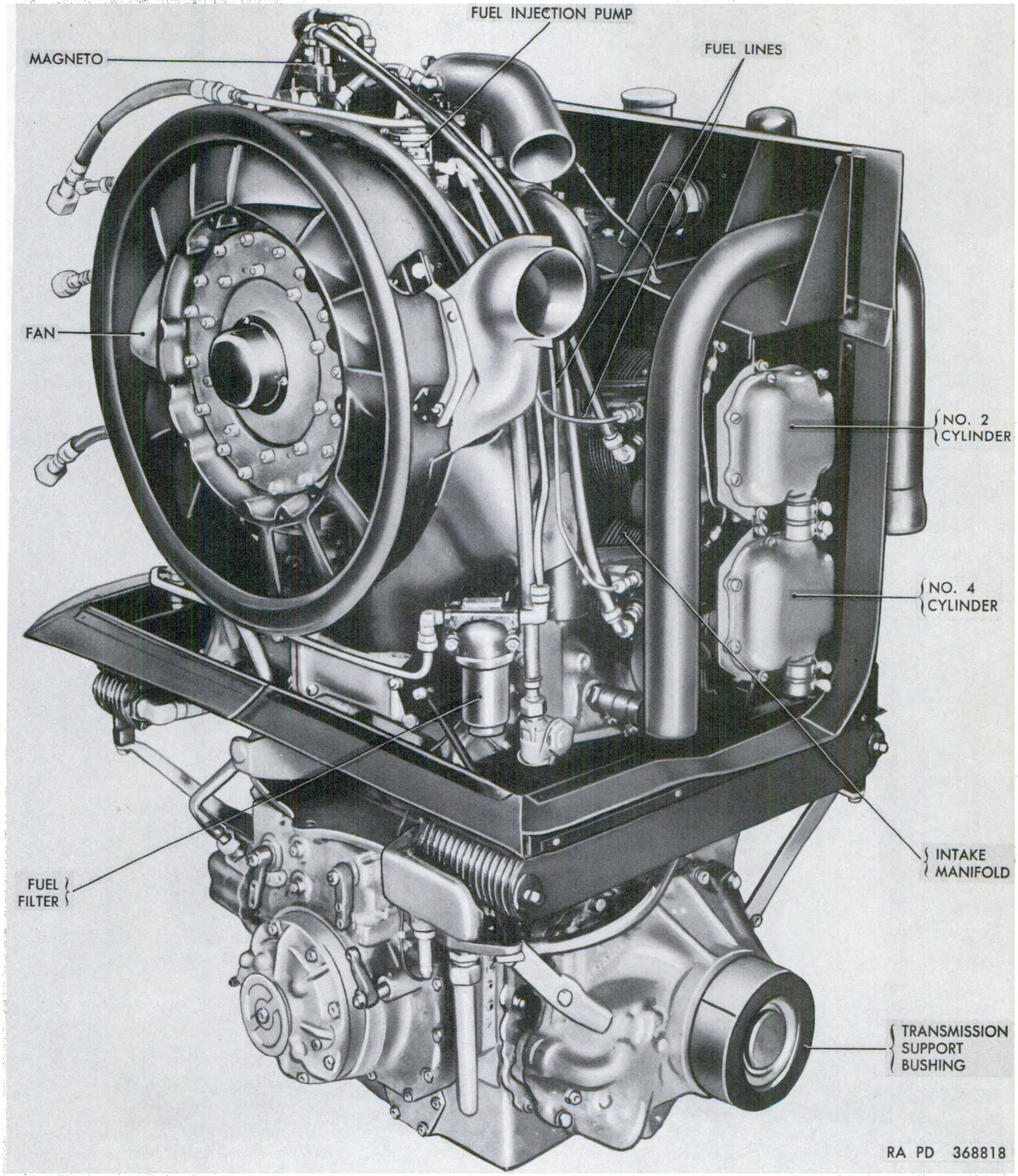

FUEL INJECTION PUMP
MAGNETO
FUEL LINES
FAN
NO. 2 CYLINDER
NO. 4 CYLINDER
INTAKE MANIFOLD
FUEL FILTER
TRANSMISSION SUPPORT BUSHING
RA PD 368818

Figure 93. Four-cylinder, opposed-cylinder engine with fuel injection system—right front view.

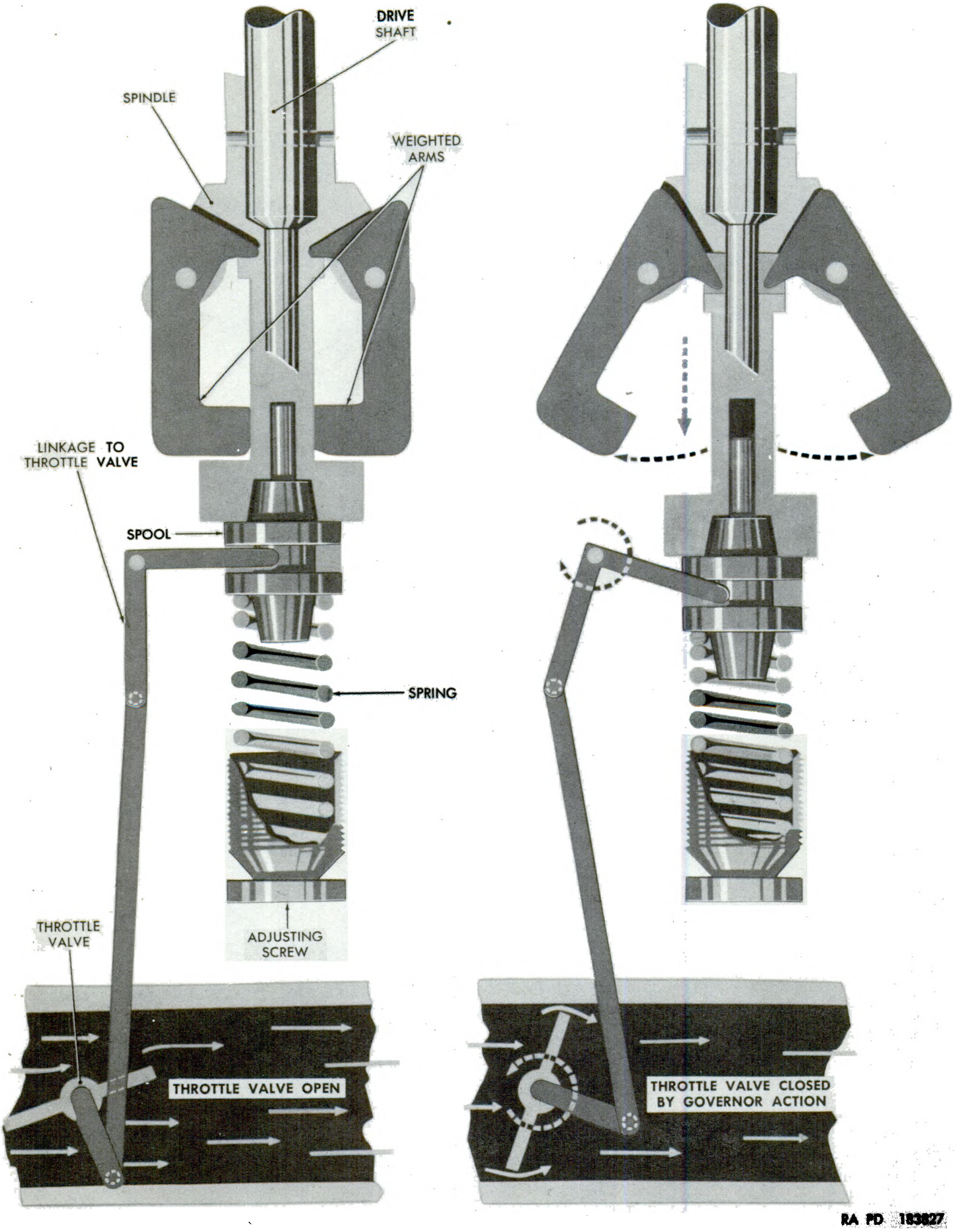

DRIVE SHAFT
SPINDLE
WEIGHTED ARMS
LINKAGE TO THROTTLE VALVE
SPOOL
SPRING
ADJUSTING SCREW
THROTTLE VALVE
THROTTLE VALVE OPEN
THROTTLE VALVE CLOSED BY GOVERNOR ACTION
RA PD 183827

Figure 94. Centrifugal governor.

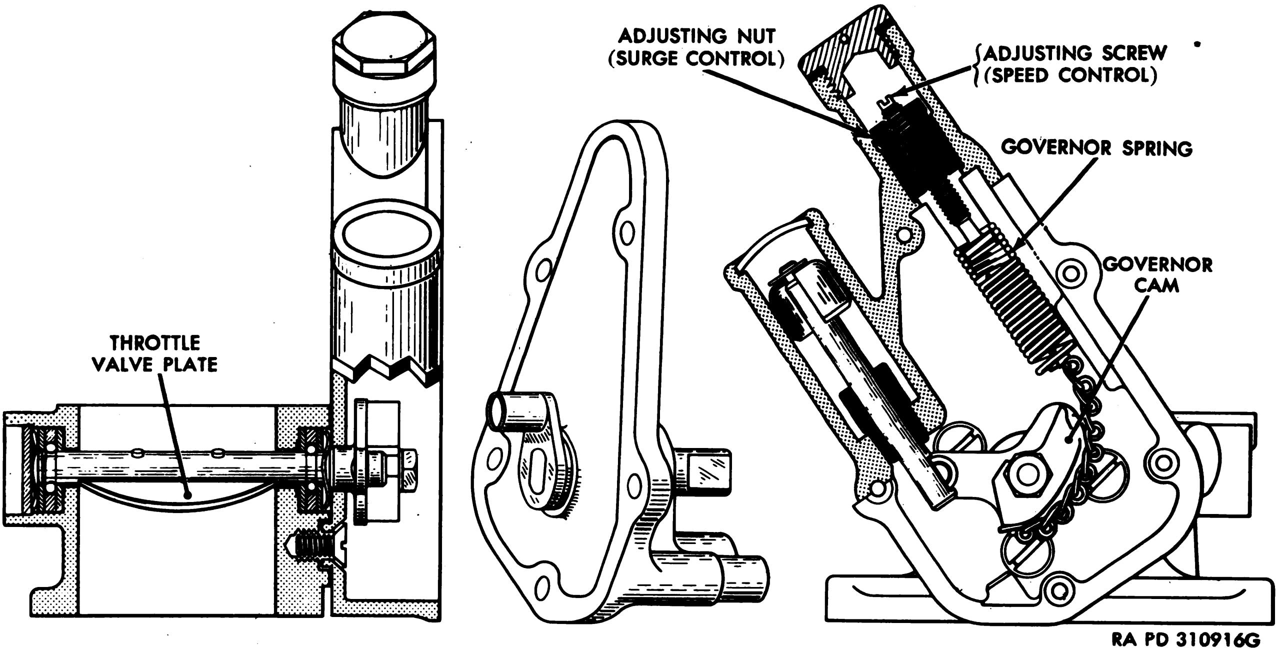

ADJUSTING NUT
(SURGE CONTROL)
ADJUSTING SCREW
(SPEED CONTROL)
GOVERNOR SPRING
GOVERNOR
CAM
THROTTLE
VALVE PLATE
RA PD 310916G

Figure 95. Velocity, or vacuum, governor.

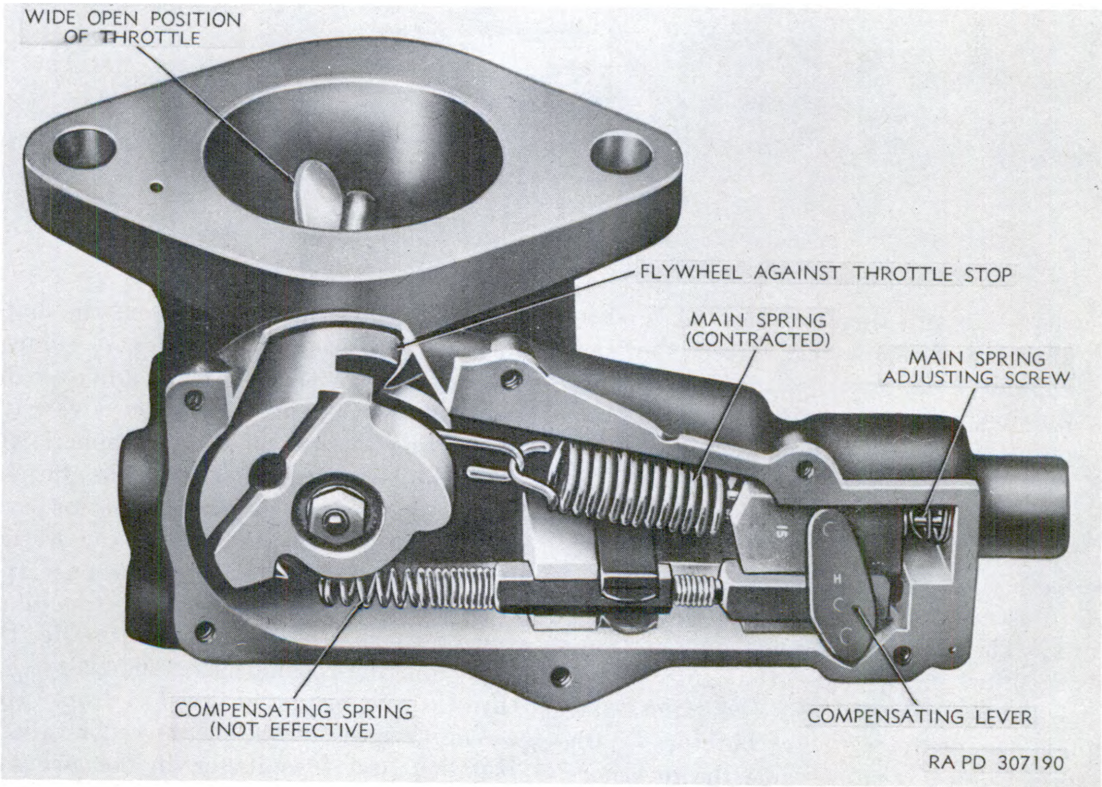

WIDE OPEN POSITION
OF THROTTLE
FLYWHEEL AGAINST THROTTLE STOP
MAIN SPRING
(CONTRACTED)
MAIN SPRING
ADJUSTING SCREW
COMPENSATING SPRING
(NOT EFFECTIVE)
COMPENSATING LEVER
RA PD 307190

Figure 96. Another type of velocity, or vacuum, governor.

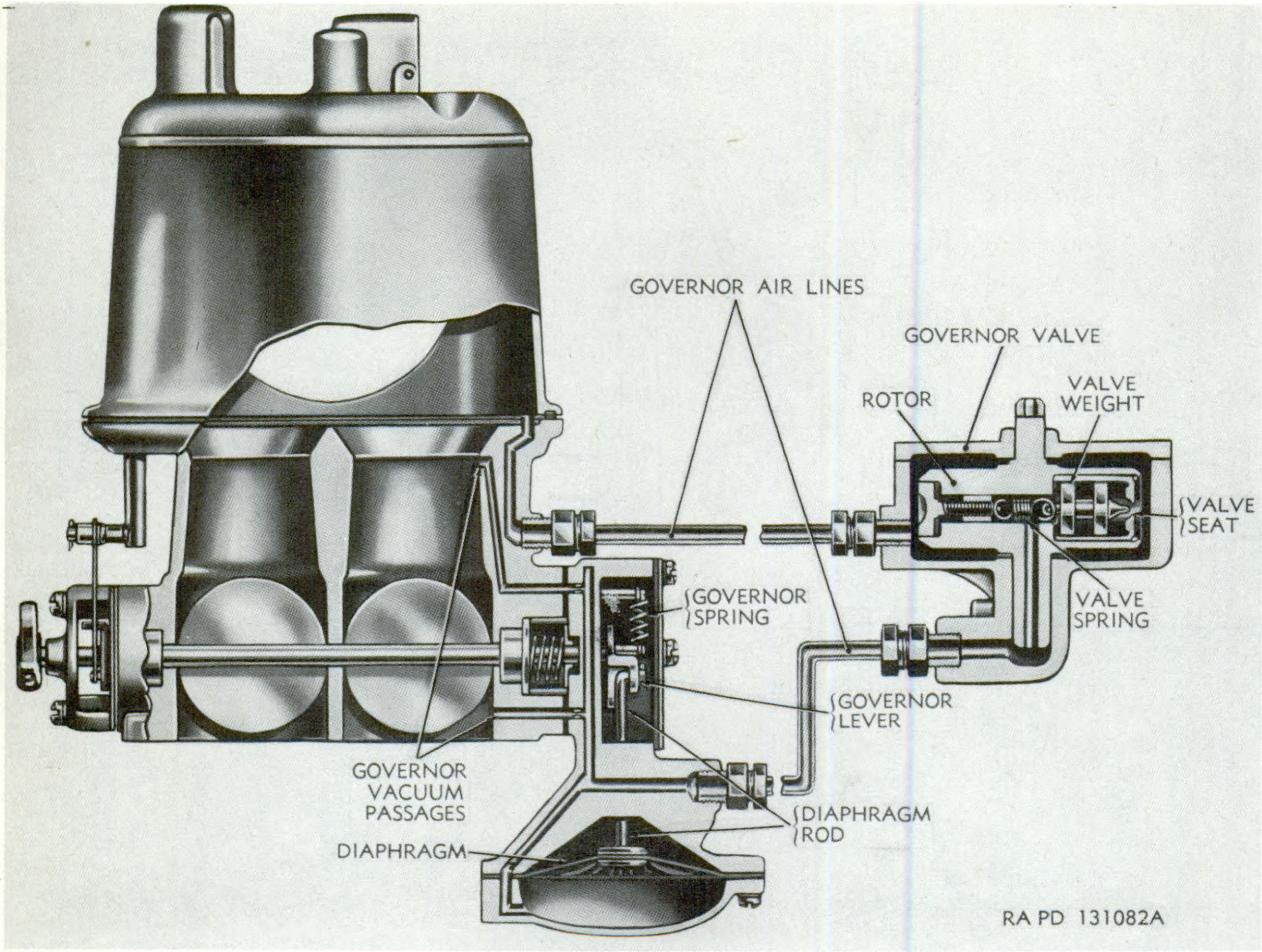


Figure 97. Centrifugal vacuum governor and carburetor with which it is used.

the valve will therefore tend to further close it and thereby excessively slow the engine. To prevent excessive speed reduction, the compensating spring becomes effective. At part throttle, the flywheel bears against it so that proper throttle opening is maintained.

c. Centrifugal-Vacuum Governor. A governor working on both principles (centrifugal and vacuum) is illustrated in figure 97. It consists of two units. The centrifugal unit, or governor, valve is mounted on or under the ignition distributor. The vacuum unit, which contains a diaphragm, is mounted on the carburetor. With engine speed below governing value, the governor-valve weight is held off its seat by a spring. Therefore, atmospheric pressure can bleed through the valve seat and into a passage in the carburetor throttle-valve body and to the lower part of the diaphragm chamber in the carburetor unit. The governor spring keeps the diaphragm in the nongoverning position. As engine speed increases, the governor-valve weight overcomes the spring tension and moves into the valve seat, thereby tending to shut off the atmospheric pressure from the lower part of the diaphragm chamber. When this happens, the pressure in this part of the diaphragm chamber is reduced to that of the manifold vacuum, thereby causing atmospheric pressure to press down on the side of the diaphragm and rod. The rod is linked to the throttle-valve shaft and the rod movement partially closes the throttle, causing engine speed to drop. However, as engine speed drops, the governor-valve weight is pulled away from its seat by the spring tension. Atmospheric pressure is once more admitted to the diaphragm chamber, causing the diaphragm to move again so that the rod allows more throttle opening. The engine is thus kept at governed speed.

CHAPTER 6

DIESEL FUEL SYSTEMS

Section I. CHARACTERISTICS OF DIESEL COMBUSTION

73. Diesel Fuels

The fuels used in modern high-speed diesel engines are a product of the petroleum refining process. They are heavier than gasoline because they are obtained from the leftovers, or residue, of the crude oil after the more volatile fuels such as gasoline and kerosene have been removed. The large, slow-running diesel engines used in stationary or marine installations will burn almost any grade of heavy fuel oil, but the high-speed diesel engines used in automotive installations require a fuel oil as light as kerosene. Although diesel fuel is different from gasoline, its specification requirements are just as exacting as those of gasoline. Of the various properties to be considered in selecting a fuel for diesel engines, the most important are cleanliness, viscosity, and ignition quality.

a. Cleanliness. Probably the most necessary property of a diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel pump and injector difficulties will occur. Diesel fuel, because it is heavier and more viscous than gasoline, will hold dirt in suspension for longer periods of time. Therefore, every precaution must be taken to keep dirt out of the fuel system or to eliminate it before it reaches the pumps. Water is more objectionable in diesel fuels than it is in gasoline because it will cause ragged operation and corrode the fuel system. The least amount of corrosion of the accurately machined surfaces in the injection equipment will cause it to become inoperative.

b. Viscosity. The viscosity of an oil is an indication of its resistance to flow. The higher the viscosity, the greater the resistance to flow. The viscosity of a diesel fuel must be sufficiently low to flow freely at the lowest temperatures encountered, but it must also be high enough to properly lubricate the closely fitted pump and injector plungers. It must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. The viscosity of a fuel also determines the size of the fuel-spray droplets which, in turn, govern the atomization and penetration qualities of the spray.

c. Ignition Quality. The ignition quality of a diesel fuel is its ability to ignite spontaneously under the conditions existing in the engine cylinder. The spontaneous-ignition point of a fuel is a function of temperature, pressure, and time. Since it would be difficult to reproduce, artificially, these factors as they exist in an engine cylinder, the best apparatus for measuring the ignition quality of a fuel is an actual diesel cylinder running under controlled operating conditions. The yardstick used for measuring the ignition quality of diesel fuels is the cetane-number scale. The cetane number of a fuel is obtained by comparing the operation of the unknown fuel in a special test engine with the operation of a known reference fuel in the same engine. The reference fuel is a mixture of alpha-methyl-napthalene, which will hardly ignite when used alone, and cetane, which will readily ignite at temperatures and pressures obtained in a diesel cylinder. The cetane number indicates the percent of cetane in a reference fuel which will just match the ignition properties of the fuel being tested.

d. Knocking. It has been observed that diesel engines knock, particularly at light loads. This knock is believed to be due to the rapid burning of the charge of fuel accumulated during the delay period between the time of injection and ignition. When the fuel is injected, it must first vaporize, then superheat until it finally reaches the spontaneous-ignition temperature under the proper conditions to start combustion. Time is required for sufficient fuel molecules to go through this cycle to permit ignition. This time is called *ignition lag* or *ignition delay.* During this same time, other portions of the fuel are being injected and are going through the same phases but behind the igniting portion; therefore, as the flame spreads from the point of ignition, appreciable portions of the charge reach their spontaneous-ignition temperatures at practically the same instant. This rapid burning causes a very rapid increase in pressure, which is accompanied by a distinct and audible knock. Increasing the compression ratio in the diesel engine will decrease the ignition lag and thereby decrease the tendency to knock. Increasing the compression ratio in a gasoline engine leads to pre-ignition and, in addition, tends to make detonation worse. Knocking in the diesel engine is affected by a large number of factors besides compression ratio, however. The type of combustion chamber, air flow within the chamber, the type of nozzle, the injection pressure conditions, the fuel temperature, and the air temperature are all factors, as are the characteristics of the fuel itself. For these reasons, more can be done in the design of a diesel engine to make it operate smoothly without detonation than is possible with the gasoline engine.

74. Combustion Chamber Design

The fuel injected into the combustion space of a diesel engine must be thoroughly mixed with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function under the principles discussed in paragraph 9*c*. None of the liquid fuel should strike the chamber walls. It is essential that the shape of the combustion chamber and the characteristics of the injected fuel spray be closely related. There are many types of combustion chambers in use today, but they are all designed to produce one effect, to bring sufficient air into contact with the injected fuel to provide complete combustion at a constant rate. All modern combustion chamber designs may be classified under one of the following headings: open, precombustion, turbulence, or divided chambers. Designs which fall under two or more headings will be covered under the heading which is the most applicable.

a. Open Chamber. The open chamber (fig. 98) is the simplest form of chamber, but its use is limited to slow-speed engines and a few high-speed 2-stroke-cycle engines. The fuel is injected directly into the combustion space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, is shaped to provide a swirling action of the air as the piston comes up on the compression stroke. There are no special cells, pockets, or passages to aid the mixing of fuel and air. This type of chamber requires higher injection pressures and a greater degree of fuel atomization than is required by the other types to obtain the same degree of mixing.

b. Precombustion Chamber. The precombustion chamber (fig. 99) is an auxiliary chamber at the top of the cylinder. It is connected to the clearance volume above the piston through a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder and distributes the fuel throughout the air in the cylinder in such a way that complete, clean burning of all the fuel is assured. On the compression stroke of the engine, air is forced into the precombustion chamber and, since the air is compressed, it becomes hot. Thus, at the beginning of injection this small chamber con-

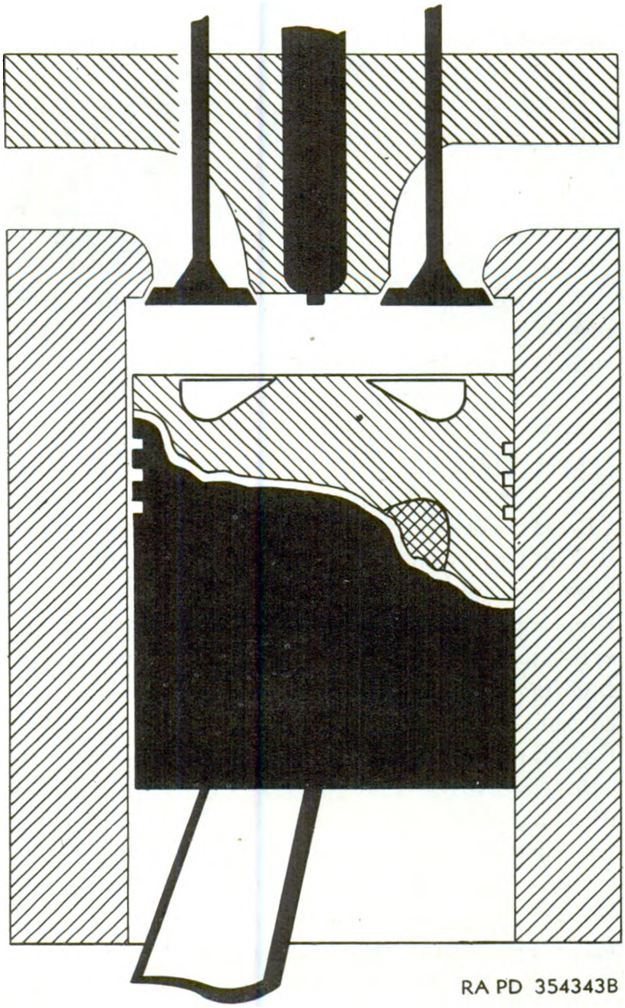
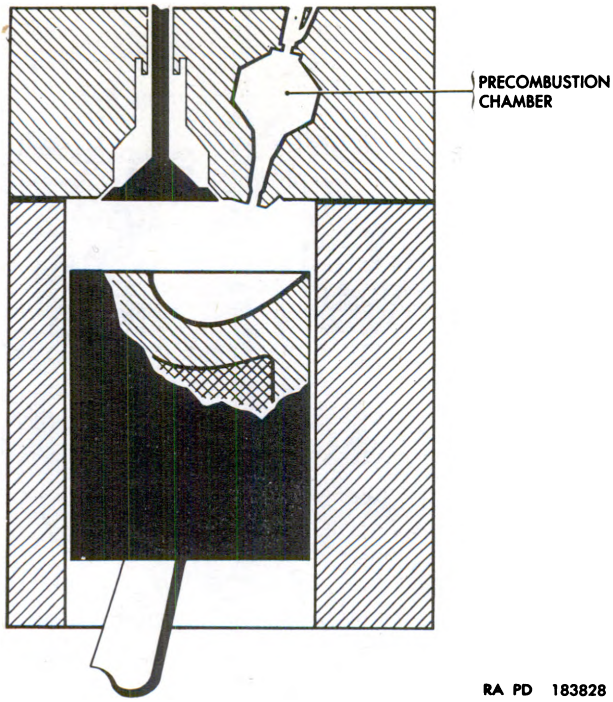


Figure 98. Diesel engine open combustion chamber.



RA PD 183828

Figure 99. Diesel engine precombustion chamber.

tains a definite volume of air. Consequently, combustion of the fuel actually starts in the precombustion chamber, since the fuel is injected into the chamber. Only a small part of the fuel is burned in this chamber because there is only a limited amount of oxygen present with which it can unite. The small predetermined amount that burns creates heat which, in turn, creates high pressure within the precombustion chamber; as injection continues, this high pressure forces the fuel at great velocity into the cylinder. There is ample oxygen present in the cylinder to burn all the fuel completely, regardless of the speed or load under which the engine is operating. Fuel injection pressures need not be as high with this type of chamber as in the open type. A coarser spray is satisfactory because the function of the chamber is to vaporize the fuel further before it enters the cylinder.

c. Turbulence Chamber. The turbulence chamber (fig. 100) is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so that a high percentage of the air between the piston and the cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical, and the opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This insures a thorough mixing of the fuel and the air, with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

d. Divided Chamber.

(1) The divided chamber, or combination precombustion chamber and turbulence chamber, probably is better known by the trade name, Lanova combustion chamber. Like the open chamber combustion system, the main volume of air remains and the principal combustion takes place in the main combustion chamber; but unlike the open chamber combustion system, the combustion is controlled. Like the turbulence-chamber type, the Lanova system depends on a high degree of turbulence to promote thorough mixing and distribution of the fuel and air; but unlike it, this entails no increase in pumping losses. Ninety percent of the com-

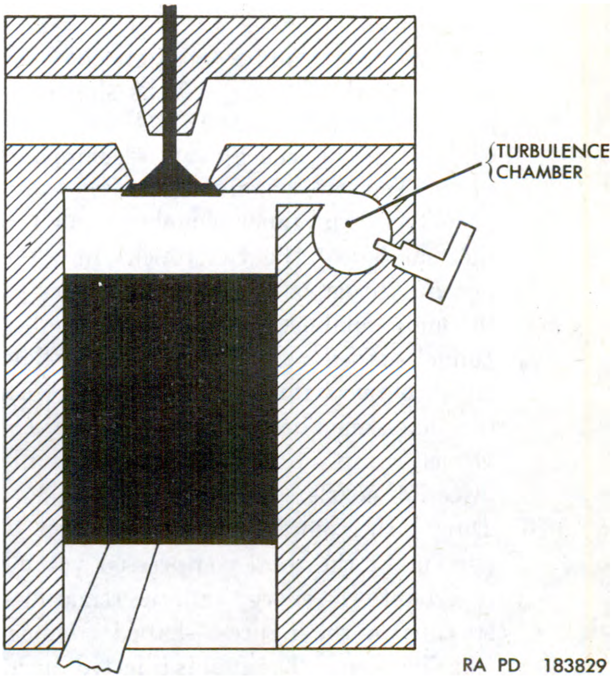


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Figure 100. Diesel engine turbulence chamber.

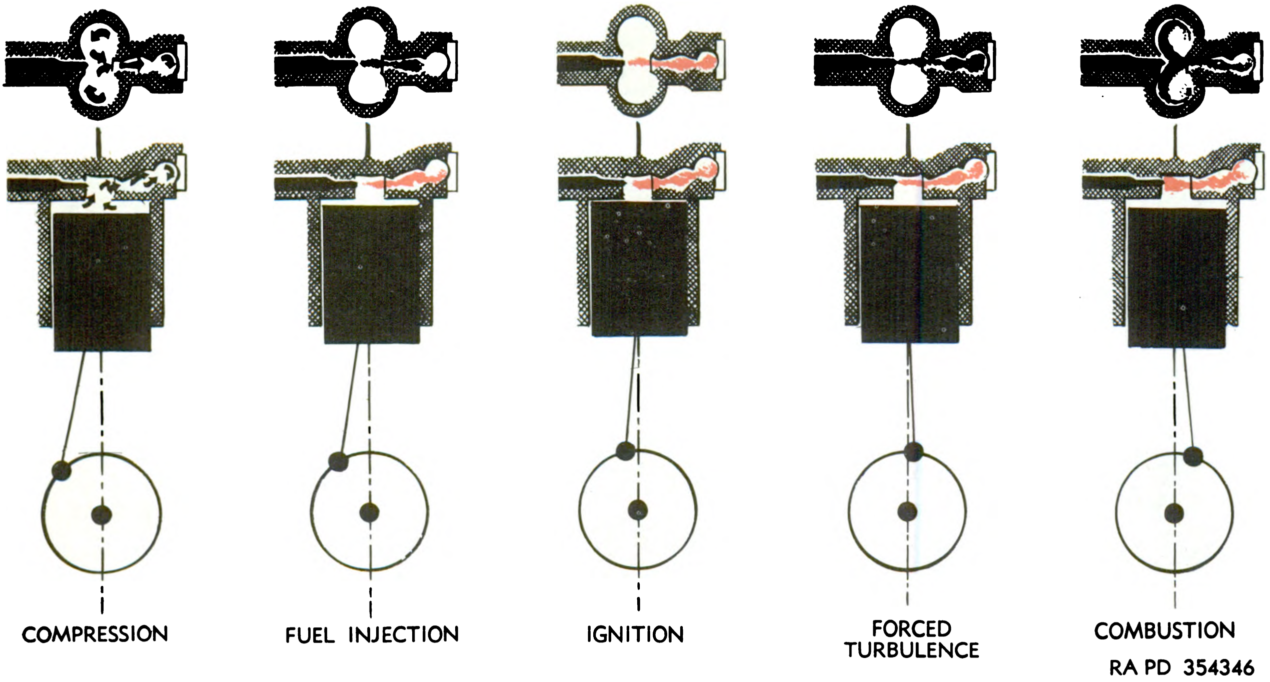
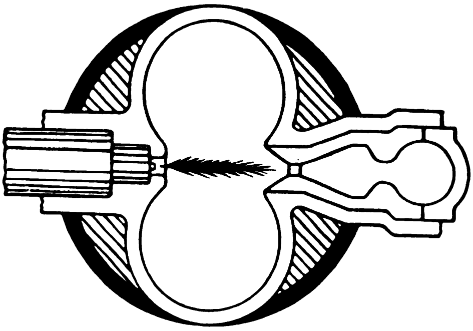


Figure 101. Lanova divided chamber—piston positions.

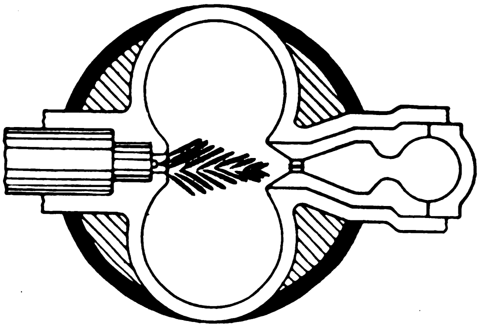
bustion chamber is directly in the path of the in-and-out movement of the valves. The turbulence in the Lanova system is dependent upon thermal expansion and not on engine speed, as are the other systems.

(2) Primarily, the Lanova system involves the combination of the figure-8-shaped combustion chamber situated centrally over the piston, and a small air chamber known as the *energy cell*, as shown in figures 101 and 102. In its latest development, this energy cell is comprised of two separate chambers, an inner and an outer. The inner chamber, which is the smaller of the two, opens into the narrow throat between the two lobes of the main combustion chamber through a funnel-shaped venturi passage. The larger outer chamber communicates with the inner one through a second venturi. Directly opposite the energy cell is the injection nozzle.

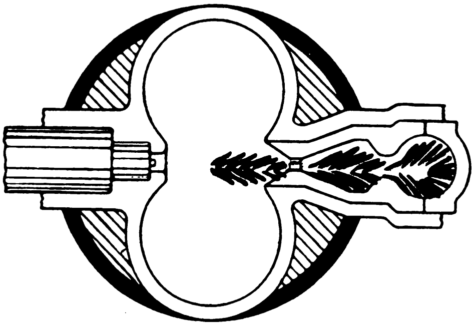
(3) During the compression stroke, about 10 percent of the total compressed volume passes into the energy cell, the remainder staying in the figure-8-shaped combustion chamber. The fuel is injected in the form of a pencil stream which passes directly across the narrow throat of the combustion chamber, most of it penetrating into the energy cell. A small portion of the boundary layer follows the curvature of the combustion chamber lobes and swirls into vortexes within them, thus, indicating a weak combustion. The fuel entering the energy cell is trapped, for the most part, in the small outer cell, but a small part passes into the larger outer cell where it meets a sufficient quantity of superheated air to explode violently. This explosion produces an extremely rapid rise to high pressure within the steel energy cell, which blows the main body of the fuel lying in the inner cell back into the main combustion chamber, where it meets the main body of air. Here, owing to the shape of the chamber, it swirls around at an exceedingly high rate of turbulence, thus burning continuously as it issues from the energy cell. Owing to the restriction of the two venturi connecting the energy cells, the blowback of fuel into the combustion chamber is controlled so that this operation consumes an appreciable period of time, producing a prolonged and smooth combustion in which the rate of pressure rise on the piston is gradual.



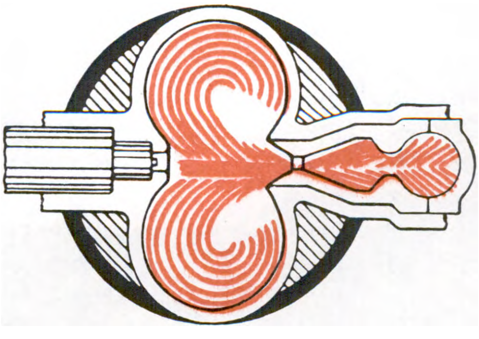
FUEL INJECTION



FUEL IGNITION



COMBUSTION IN ENERGY CELL



COMBUSTION IN MAIN CHAMBER

RA PD 354347

Figure 102. Lanova divided chamber—fuel combustion.

Section II. INJECTION SYSTEMS

75. Fuel Injection Principles

a. Methods. There are two methods of injecting the fuel against the air pressure in the cylinder of a diesel engine: air injection, where a blast of air from an external source forces a measured amount of fuel into the cylinder; and solid injection, where the fuel is forced into the cylinder by a direct pressure on the fuel itself. The discussion which follows will be limited to those systems utilizing solid injection, because the air injection system has been proved impractical for automotive installations.

b. Fuel Atomization and Penetration. The fuel spray entering the combustion chamber must conform to the shape of the chamber so that the fuel particles will be well distributed and thoroughly mixed with the air (par. 74). The shape of the spray is determined by the degree of atomization and penetration produced by the orifice through which the fuel enters the chamber. *Atomization* is the term used to denote the size of the drops into which the fuel is broken, whereas penetration is the distance from the orifice which an oil drop attains at a given phase in the injection period. Roughly speaking, the penetration of a spray depends on the length of the nozzle orifice, the diameter of the orifice outlet, the viscosity of the fuel, and the pressure on the fuel. Penetration increases with the increasing ratio of the length of the orifice to its diameter; atomization, however, is increased by decreasing the ratio of the length of an orifice to its diameter. Since penetration and atomization are mutually opposed to each other, a compromise is necessary if uniform fuel distribution is to be obtained. The amount of pressure required for efficient injection is dependent on the pressure of the air in the combustion chamber, the size of the orifice, the shape of the combustion chamber, and the amount of turbulence produced in the combustion space.

c. Function of Injection System. It is impossible to cover the operation and construction of the many types of modern injection systems in this text. However, the operation of a few of the more common systems will be discussed. Emphasis will be placed on functional operation rather than mechanical details. The function of each system is to meter the fuel accurately, deliver equal amounts of fuel to all cylinders at a pressure high enough to insure atomization, and control the start, rate, and duration of injection. If this three-fold function is kept in mind, the operation of the various systems will be more easily understood.

76. Multiple-Unit Injection Pump System

a. General Operation. In this system each cylinder has an individual injection pump which meters the fuel and delivers it under high pressure to the spray nozzles which lead into the combustion chambers. The pumps are mounted in a common housing, are operated by a common camshaft, and utilize the same control mechanism to insure an equal amount of fuel in each cylinder at the proper time. The flow of fuel in a typical multiple-unit injection pump system is shown in figures 103 and 104. Diesel fuel oil flows from the supply tank through a fuel filter to the fuel supply pump. The fuel supply pump forces the fuel through an additional filter to the injection pumps. The fuel injection pumps force a measured amount of fuel through high-pressure lines to the spray nozzles in the combustion chambers. Surplus fuel flows from the injection pumps through a check valve on the common housing and is returned to the fuel supply tank.

b. Fuel Injection Pumps.

(1) A phantom cross-sectional view of a typical multiple-unit injection pump is shown in figure 103. The unit is mounted on the engine in such a manner as to permit it to be driven by the engine. The pump camshaft, near the bottom of the housing, is carried on ball bearings. The cam lobes cause the upward movement of the plungers, and springs produce the downward motion. The cams are arranged to actuate the individual pumps in the same sequence as the firing order of the engine to eliminate the necessity for crossing lines leading from the pumps to the spray nozzles. On the 4-stroke-cycle engine, the injection pump is driven at one-half engine speed; on the 2-stroke-cycle engine it is driven at engine speed.

(2) The individual pumps are the lapped-plunger constant-stroke metering bypass type. The quantity of fuel delivered to the spray nozzle is regulated by

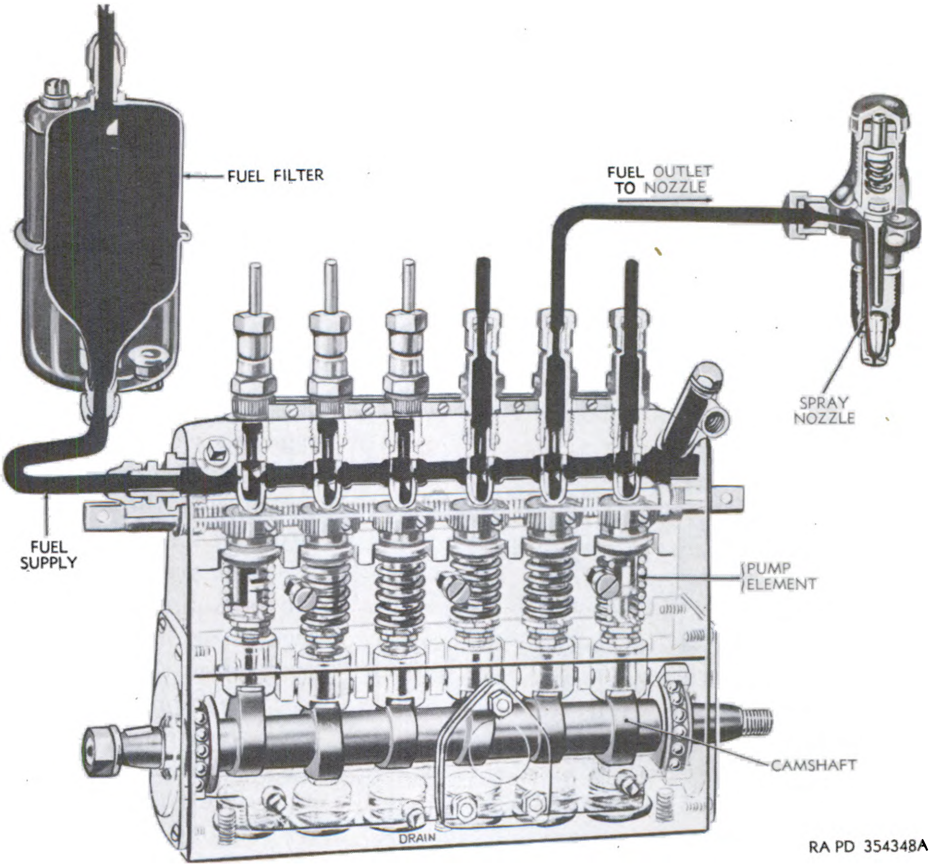


Figure 103. Fuel flow in multiple-unit diesel engine fuel injection pump.

the time the plunger covers the bypass port. The plunger stroke remains constant at all loads. The injection must be timed to occur as demanded by the requirements of the engine. Volumetric control is effected by rotating the plunger. Two ports lead to the plunger barrel as shown in figures 104 and 105: one is the inlet port and the other is the bypass port. The plunger has a groove around its circumference, which has a circular lower edge and helical upper edge. The space thus formed communicates with the top face of the plunger through a vertical slot. Hence, any fuel above the plunger will flow down the vertical slot and fill the helical space. At the lower end of the plunger are two lugs which fit in corresponding slots in the bottom of an outer sleeve fitted around the pump barrel. The upper portion of the sleeve is fastened to a gear segment which meshes with a horizontal toothed rack. Any movement of the rack rotates the outer sleeve and plunger relative to the bypass port in the stationary pump barrel.

(3) Fuel from the sump rushes into the barrel as soon as the upper edge of the plunger opens the two opposite ports in the barrel. This action begins during the downward stroke of the plunger, and the ports remain open until the plunger starts moving upward. After the plunger covers the ports on its upward stroke, the pressure exerted on the fuel causes the spring-loaded delivery valve to lift off its seat, thereby, permitting the fuel to discharge into the tubing which leads to the spray nozzle. The delivery of the fuel ceases as soon as the helix on the plunger uncovers the bypass port in the barrel. At this instant, the pressure chamber communicates with the sump by way of the vertical groove and the helix

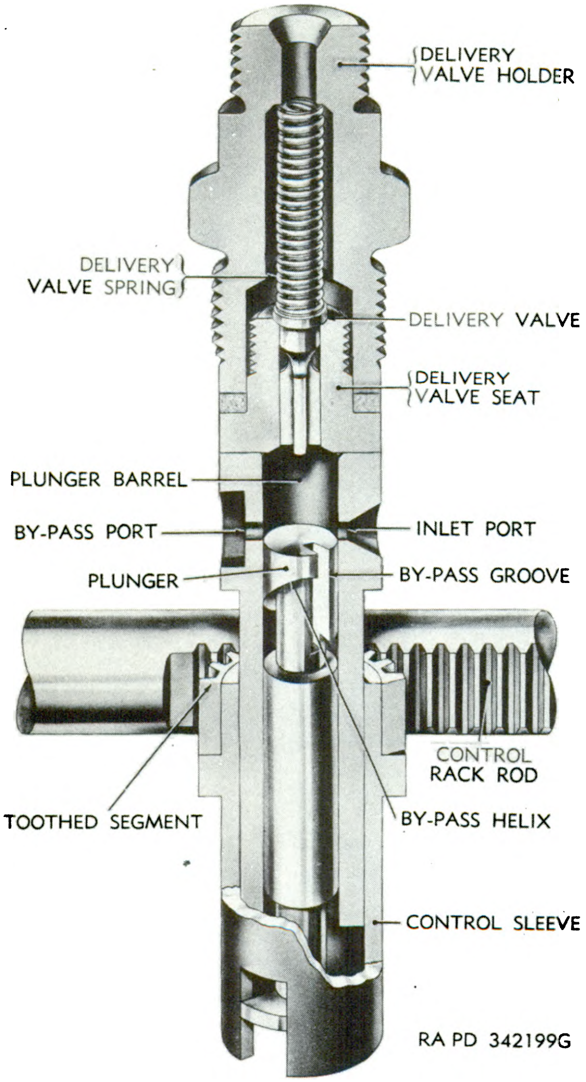


Figure 104. Fuel injection pump element and control rack.

on the plunger, thus relieving the pressure in the barrel. The delivery valve is quickly returned to its seat by the combined action of its spring and the great difference in pressure that exists between the barrel and the high-pressure line. In returning to its seat, the delivery valve performs a double function, it prevents excessive draining of the fuel from the high-pressure line and it relieves the pressure in the high-pressure line. This pressure relief is accomplished by an accurately lapped displacement piston on the delivery valve. Before the delivery valve actually reseats, it reduces the pressure in the high-pressure line by increasing the volume therein by a quantity equal to the volume of the displacement piston.

(4) The positions of the plunger from no fuel to maximum fuel delivery are shown in figure 106. For maximum delivery, the plunger is positioned in the barrel so that it will nearly complete its stroke before the helix indexes with the bypass port. For zero delivery, the plunger is turned in its barrel until the vertical slot registers with the bypass port. In this position, the pressure chamber is connected with the sump during the entire stroke of the plunger. Any position between no fuel to maximum fuel delivery can be obtained by moving the control rack in or out, as the movement of the rack causes the plunger to rotate a proportionate amount. The same rack controls the position of all the plungers simultaneously, thereby insuring the injection of equal amounts of fuel in each cylinder of the engine.

c. Spray Nozzles and Nozzle Holders.

(1) *General.* For proper engine performance, the fuel oil must be injected into the combustion space in a definite spray form. This is accomplished by the spray nozzle, which is held in the correct position in the cylinder head by the nozzle holder. The type of unit most commonly used with the multiple-unit injection pump is shown in a cross section view in figure 107.

(2) *Operation.* The fuel delivered by the injection pump flows through the high-pressure line and enters the nozzle-holder inlet stud. Then it passes through the edge filter, flows through the ducts in the holder and nozzle body, and flows down into the pressure chamber of the spray nozzle above the valve seat. There, the pressure of the fuel oil acts on the differential area of the nozzle valve. At the moment when the pressure of the fuel exceeds the pressure exerted by the adjusting spring, the nozzle valve is lifted off its seat and the fuel is forced through the orifices and sprayed into the combustion chamber of the engine. The nozzle valve returns to its seat after the

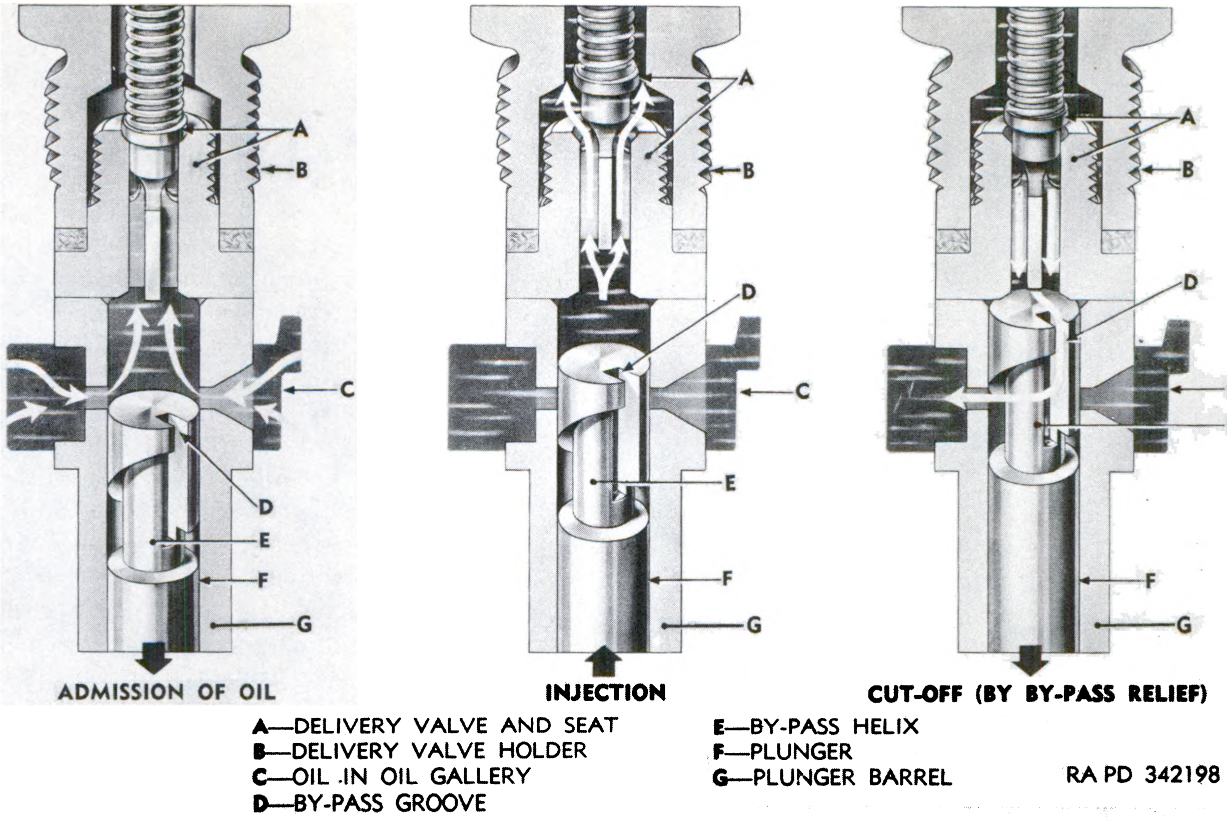


Figure 105. Fuel injection pump plunger.

injection pump has ceased to deliver fuel. The hydraulic opening pressure of the spray nozzle may vary from 1,000 to 4,000 psi, depending on engine combustion-chamber requirements. A certain amount of seepage of fuel between the lapped surfaces of the nozzle valve and its body is necessary for lubrication. This leakage oil accumulates around the spindle and in the spring compartment, from which it drains through the leak-off connection provided for that purpose.

(3) *Spray nozzles.* Because of the widely differing requirements in the shapes of the fuel spray for various combustion chamber designs, and because of the wide range in engine power demands, there is a large variety of nozzles used with multiple-unit injection pump systems. Essentially, there are two basic groups: pintle nozzles and hole nozzles (fig. 108). Pintle nozzles are generally used in engines having precombustion, turbulence, or divided chambers, whereas the hole nozzles are generally used with open combustion chamber designs.

(*a*) In pintle nozzles (fig. 109), the nozzle valve carries an extension at its lower end in the form of a pin (pintle) which protrudes through the hole in the nozzle bottom. This requires the injected fuel to pass through an annular orifice, producing a hollow, cone-shaped spray, the nominal included angle of which may be from 0° to 60°, depending on the combustion system requirement. The projection of the pintle through the nozzle orifice induces a self-cleaning effect, discouraging the accumulation of carbon at this point.

(*b*) A specific type of pintle nozzle extensively used in small-bore high-speed diesel engines is the throttling nozzle. It differs from the standard pintle nozzle in that the pintle projects from the nozzle body for a much greater distance, and the orifice in the bottom of the nozzle body is much longer. These differences are readily apparent from the cross-sectional views in figure 109. The outstanding feature of the throttling nozzle is its control of the rate at which fuel is injected into the combustion chamber. The pintle extends through the nozzle orifice when no fuel is being injected, and hydraulic pressure from the injection pump causes the pintle to rise for fuel delivery. At the beginning of the injection period, only a small quantity of fuel is injected into the chamber because the straight section of the pintle is in the nozzle orifice. The volume of the fuel spray is then progressively increased as the pintle is lifted higher, because the straight section leaves the orifice and the tapered tip of the pintle in the orifice provides a larger opening for the flow of fuel. Another type of throttling nozzle has its pintle flush with the nozzle-body tip for no fuel delivery and extended through the body for maximum fuel delivery. In this type, fuel under high pressure from the injection pump acts on the seat area of the pintle, forcing it outward against a preloaded spring. This spring, through its action on a spring hanger, also returns the pintle to its seat, sealing the nozzle against further injections or dribble when the line pressure is relieved at the pump. When the pintle moves outward, due to fuel pressure, an increasingly larger orifice area is opened around the flow angle of the pintle.

(*c*) The hole nozzles have no pintle but are basically similar in construction to the pintle type. They have one or more spray orifices which are straight, round passages through the tip of the nozzle body beneath the valve seat (fig. 108). The spray from each orifice is relatively dense and compact, and the general spray pattern is determined by the number and arrangement of the holes. As many as 18 spray holes are provided in the larger nozzles, and the diameter of these drilled orifices may be as small as 0.006 inch. The spray pattern may or may not be symmetrical, depending on the engine combustion chamber design and fuel distribution requirements.

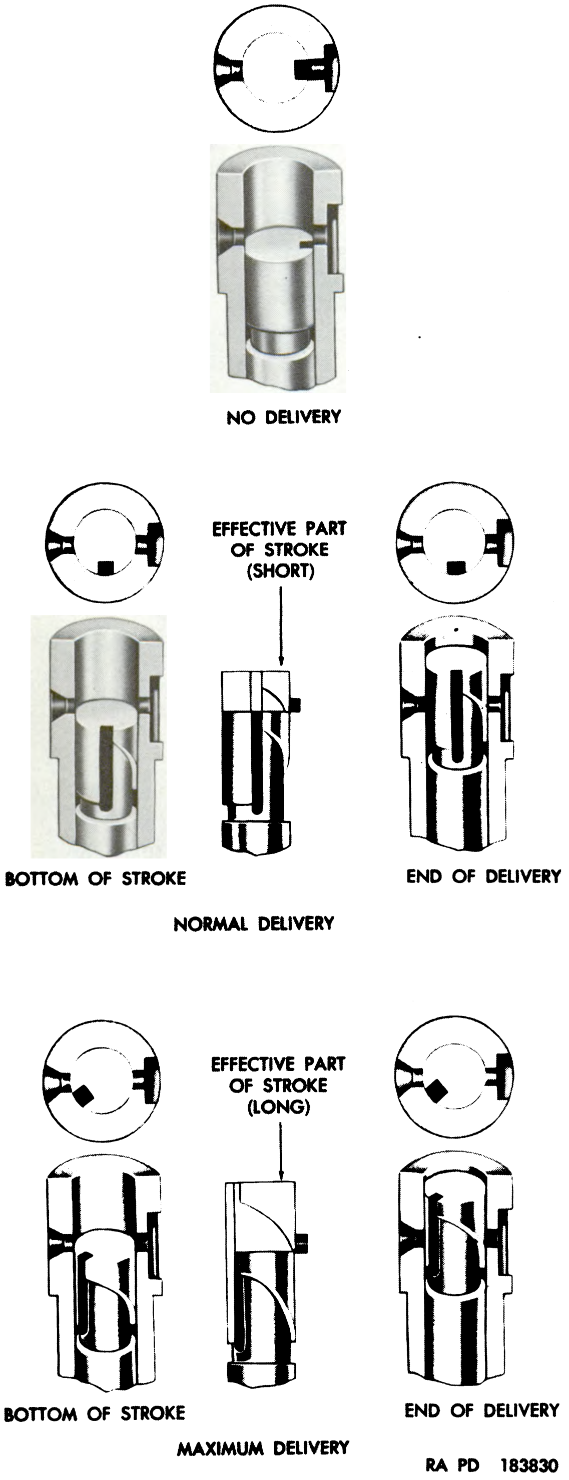


Figure 106. Injection pump plunger positions for varying amounts of fuel delivery.

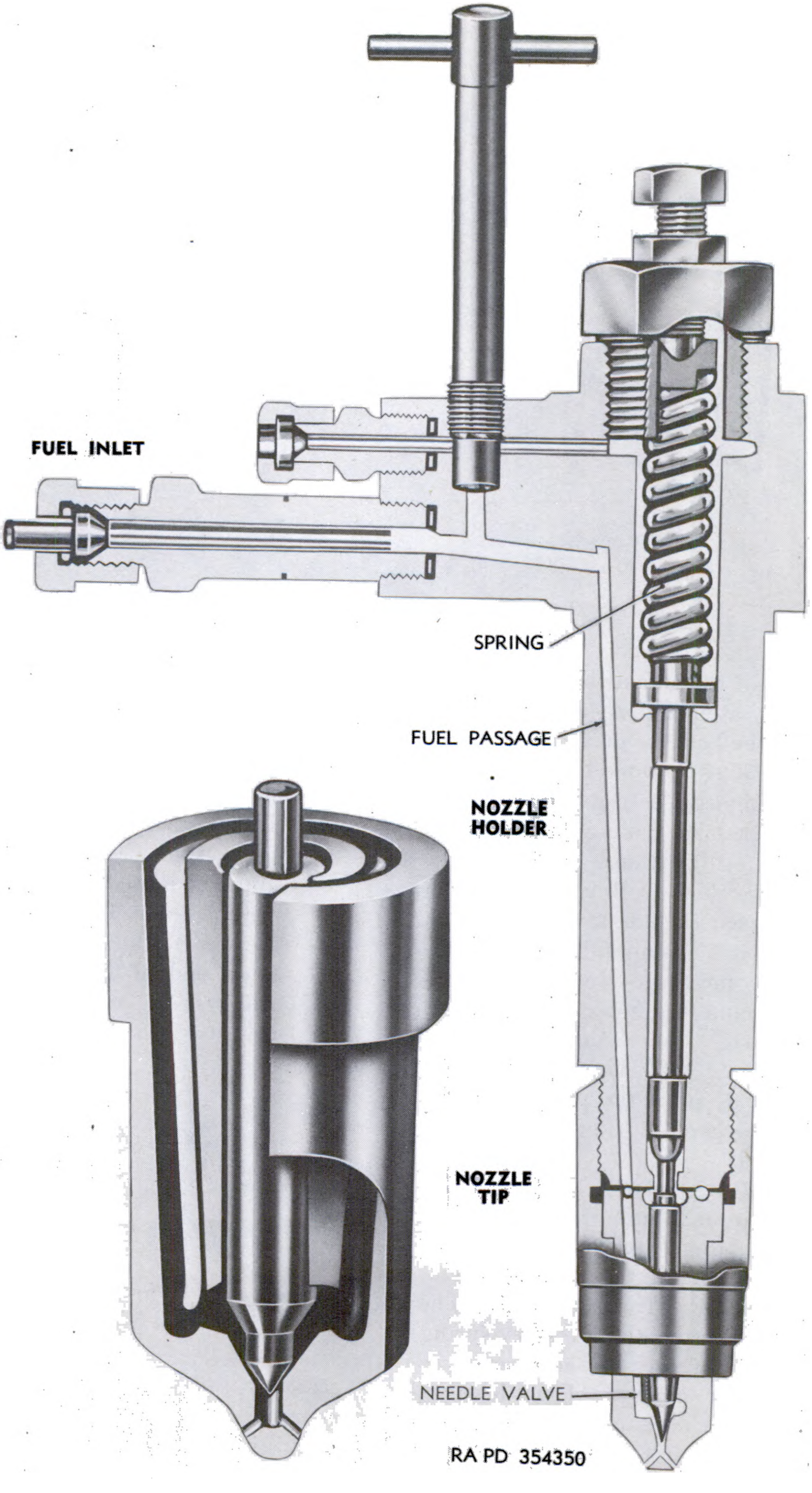

FUEL INLET
SPRING
FUEL PASSAGE
NOZZLE HOLDER
NOZZLE TIP
NEEDLE VALVE
RA PD 354350

Figure 107. Spray nozzle for multiple-unit fuel injection pump—cross-sectional view.

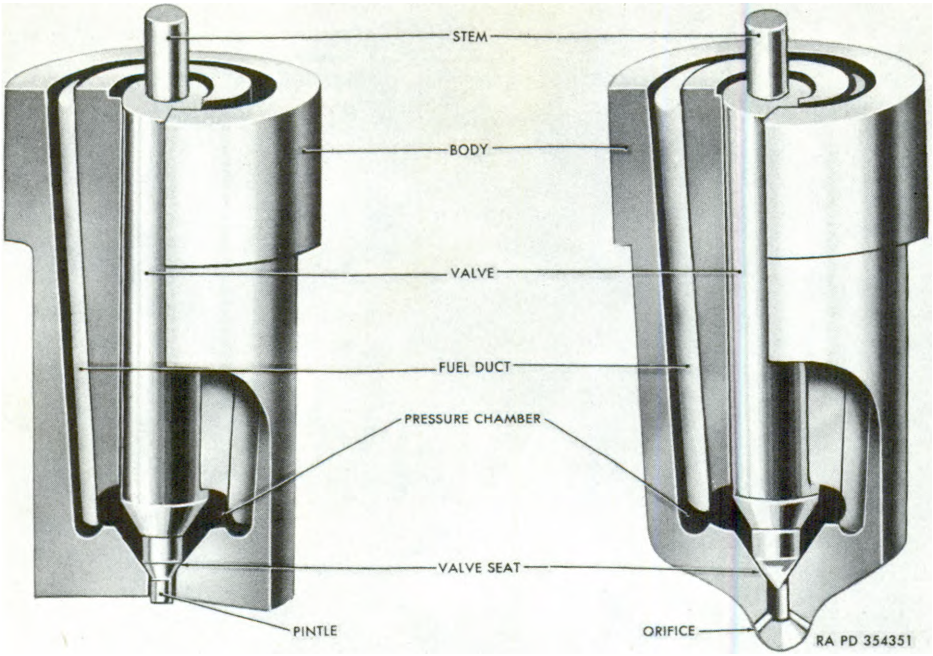


Figure 108. Pintle and hole fuel nozzles.

The size of the hole determines the degree of atomization attained. The smaller the hole the greater the atomization, but if the hole is too small, it will be impossible to get enough fuel into the chamber during the short time allowed for injection. If the hole is too large, there will be an overrich mixture near the nozzle tip and a lean mixture at a distance from it. Multiple-hole nozzles overcome this difficulty, because the holes can be drilled small enough to provide proper atomization and a sufficient number can be provided to allow the proper amount of fuel to enter during the injection period.

(4) *Nozzle holders.* The nozzle holder holds the spray nozzle in its correct position in the engine cylinder, provides a means of conducting fuel oil to the nozzle, and conducts heat away from the nozzle. The holder also contains the necessary spring and a means of pressure adjustment to provide proper action of the nozzle valve. The component parts of a typical nozzle holder are shown in figure 107. The body has drilled passages for conducting the fuel from the inlet connection to the nozzle, and its lower end is provided with an accurately ground and lapped surface which makes a leakproof and pressure-tight seal with the corresponding lapped surface at the upper end of the nozzle. The nozzle is secured by means of the cap nut, as shown in figure 107. At its upper end, the nozzle valve has an extension of reduced diameter (referred to as the *stem*) which makes contact with the lower end of the spring-loaded spindle. Adjustment of nozzle-valve opening pressure is accomplished by means of the

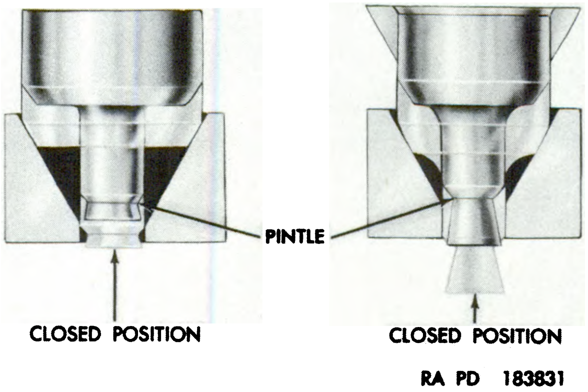


Figure 109. Action of pintle (left) and throttling pintle fuel nozzles—cross sectional view.

spring pressure-adjusting screw. The adjustment in other types of holders, which are not illustrated, is accomplished by means of spacers between the top of the spring and the upper spring seat.

77. Wobble-Plate Pump System

a. The only major difference between the wobble-plate pump system and the injection system (par. 76) lies in the injection-pump unit itself. In the wobble-plate pump, all the pump plungers are actuated by a wobble plate instead of the customary camshaft having an individual cam for each pump plunger. Also, the metering of the fuel is accomplished by a single axially located rotary valve in the wobble-plate unit, whereas the rotary movement of the indivdual plungers controls the amount of fuel in the multiple-unit injection-pump system.

b. The principles of a wobble-plate pump are illustrated in figure 110. A plate is mounted on a shaft and set at an angle to it so that, as the shaft rotates, the plate also rotates and any particular spot on the plate will not only rotate but will also move laterally. The pump derives its name from the fact that the plate appears to wobble back and forth as it rotates. The end of a push rod is placed in a guide plate which lays against the wobble plate. The push rod is held in a bore in the pump body so that it can move only in a direction parallel to the wobble-plate shaft. The rotation of the wobble plate then causes the guide plate to wobble, thus moving the push rod back and forth. The push rod is connected to a pump plunger (fig. 111) so that the movement to the left actuates the pump on its delivery stroke and a spring returns it on the suction stroke. The injection pump unit contains one pumping plunger for each engine cylinder. Half the number of plungers are always moving to the right on their filling stroke, the other half are moving to the left on the delivery or injection stroke.

c. The rotary metering valve is driven by the same shaft that drives the wobble plate. The rotary valve consists of a lapped cylindrical shaft closely fitted in a barrel to prevent fuel from escaping at its ends. Fuel is admitted to the barrel at the center of the valve, which contains a spool-like reduction in diameter. This reduction in diameter acts as a fuel reservoir. The recess portion of the valve is in the shape of a band broken by a triangular land of the same diameter as the ends of the valve (fig. 112). A separate port leads from the recess to the end of each plunger bore. Through this port the plunger cavity is supplied with fuel. The angular relation of the valve and the wobble plate is such that the valve land will cover each port at the time the respective plunger is at approximately its maximum speed in the direction of discharge. Prior to port closing and after port opening (caused by the movement of the triangular land across the port), fuel displaced by the plunger in its pressure stroke flows back through the port into the recess. The fuel trapped in the plunger cavity when the port is closed is forced through a check valve into the high-pressure lines and on to the spray nozzle.

d. To obtain zero delivery, the valve is moved endwise (to the right of fig. 112) to a position where the ports are never closed by the land. The movement of the plungers then merely causes fuel to move in and out through the ports without building up a pressure sufficient to open the deliv-

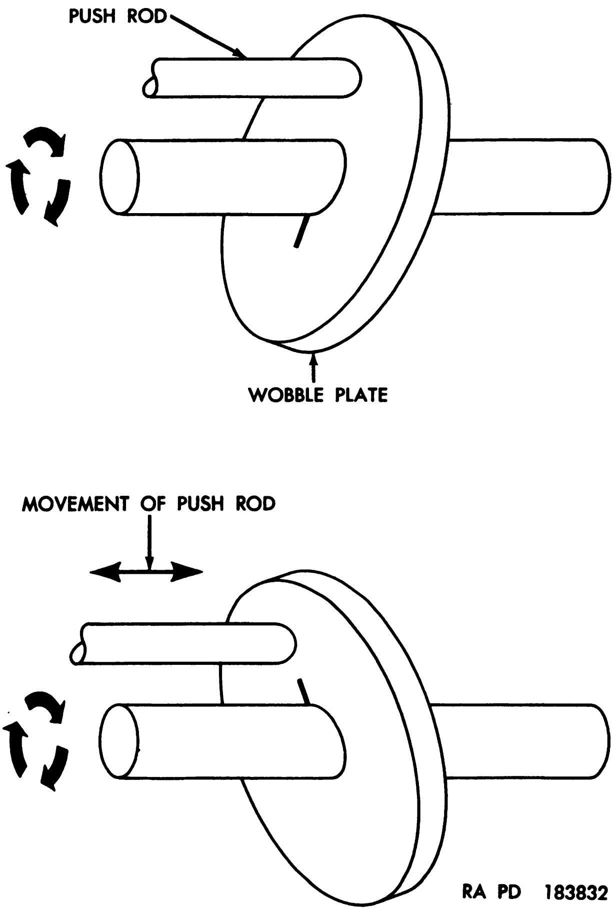


Figure 110. Wobble-plate pump principle.

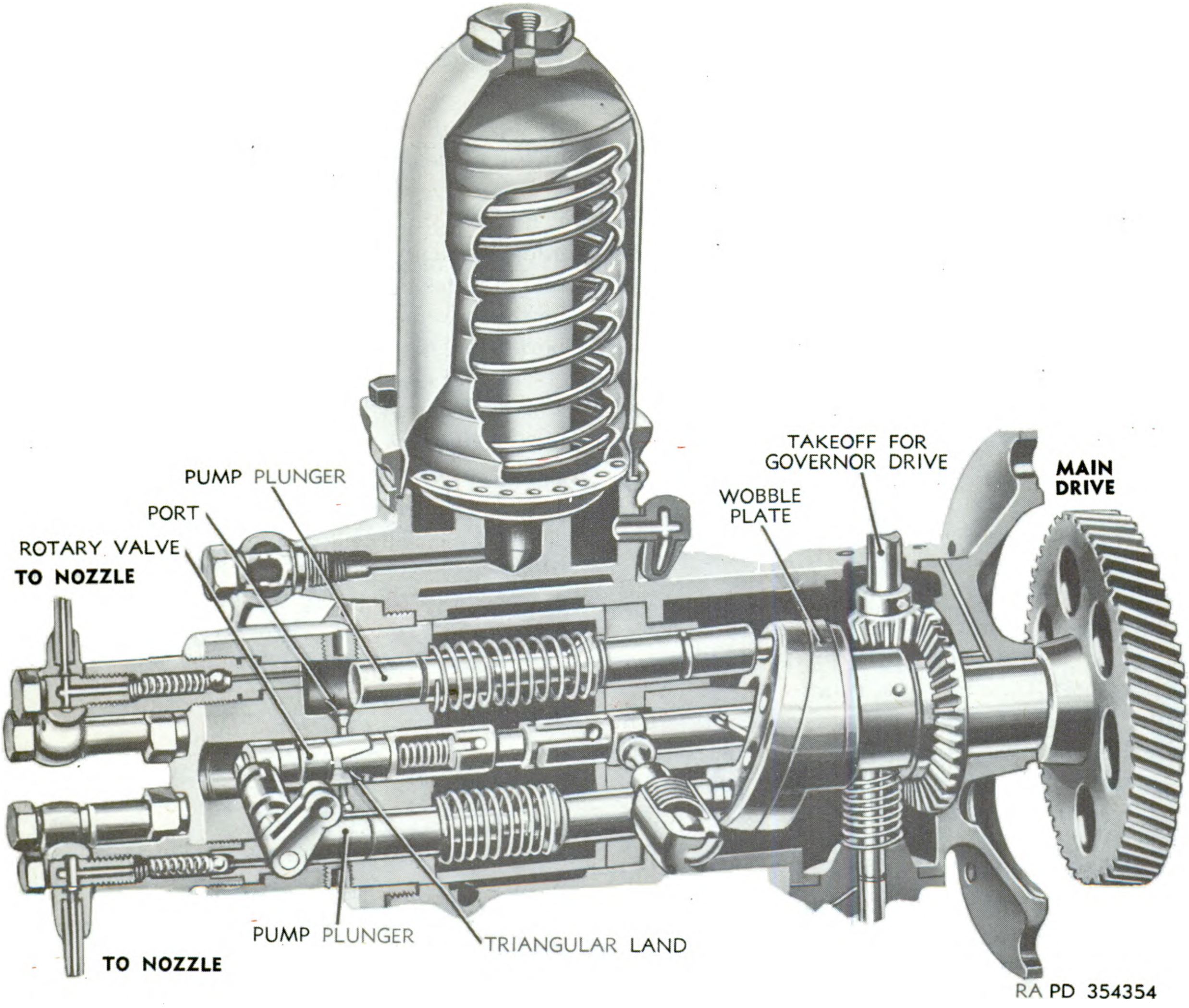


Figure 111. Wobble-plate fuel pump unit.

ery valves and cause injection. To cause the pump to deliver fuel, the valve is moved endwise so that, during rotation, the triangular-shaped land closes the port when the plunger is moving in the discharge direction. Further endwise movement of the valve causes a wider portion of the land to pass across the ports, thus, increasing the duration and the quantity of fuel injected. Each port is closed for exactly the same duration of plunger travel and therefore exactly the same quantity of fuel is delivered to each of the engine cylinders.

78. Distributor-Type System

The distributor injection system used in automotive diesel engines is classed as a low-pressure system in that pumping, metering, and distribution operations take place at low pressure. The high pressure required for injection is built up in the injector at each cylinder. A schematic diagram of the flow of fuel is shown in figure 113. A suction gear pump lifts fuel from the tank and delivers it to the float chamber, from which a second gear pump delivers it, at low pressure, to the distributor. Fuel passes through the distributor to the metering pump, then through the distributor again, and on to the injector where it is injected into the cylinder.

a. Distributor. The distributor consists of a rotating disk and a stationary cover to which are connected fuel lines running to individual injectors. The disk and cover have a series of holes which, when properly indexed, form passages from the fuel supply pump to the metering pump.

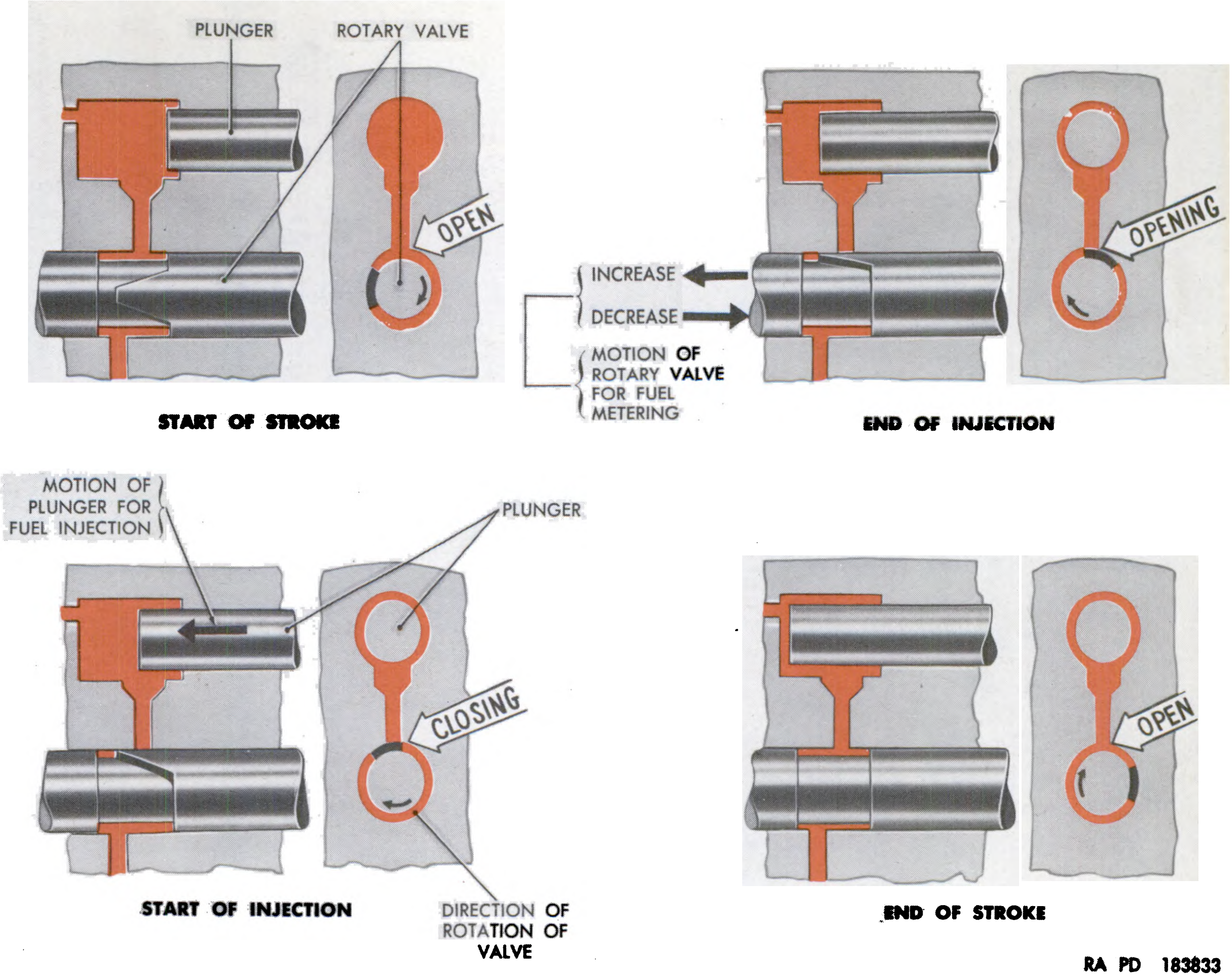

PLUNGER
ROTARY VALVE
OPEN
START OF STROKE
INCREASE
DECREASE
MOTION OF ROTARY VALVE FOR FUEL METERING
OPENING
END OF INJECTION
MOTION OF PLUNGER FOR FUEL INJECTION
PLUNGER
CLOSING
START OF INJECTION
DIRECTION OF ROTATION OF VALVE
OPEN
END OF STROKE
RA PD 183833

Figure 112. Four strokes in action of rotary valve and single pump plunger.

This occurs when the metering plunger moves down on its suction stroke and thus permits the barrel to fill with oil. The disk continues to rotate and lines up with the correct discharge hole in the cover just as the metering plunger rises by action of the main fuel-pump cam. This forces the fuel into the proper injector line.

b. Metering Units. The metering pump is a closely fitted reciprocating pump, obtaining its motion through a link from the plunger lever. The plunger lever is operated by a vertical lever controlled in turn by an eccentric rocker lever running directly off a cam on the fuel pump main shaft. The position of the vertical lever in the eccentric of the rocker lever determines the travel of the plunger lever and, consequently, the travel of the metering plunger (fig. 114). As the metering plunger starts upward on its controlled stroke, it pushes fuel to the injector through passages formed by the rotating distributor disk. The stroke of the metering plunger, which determines the amount of fuel going to each injector, is varied by changing the position of the vertical lever between the stop pins in the cam rocker lever. When the roller is against the inside stop pin, there is no travel on the vertical lever or on the metering plunger, consequently no fuel is going to the engine. If the vertical lever is moved over to the outside pin, the stroke of the metering plunger is sufficient to deliver enough fuel to the engine for full speed and load.

c. Injector. The injector consists of a forged body with a properly fitted plunger (fig. 115). This plunger is forced down against spring action by a rocker arm actuated by push rods from the engine camshaft. Mounted on the end of the body

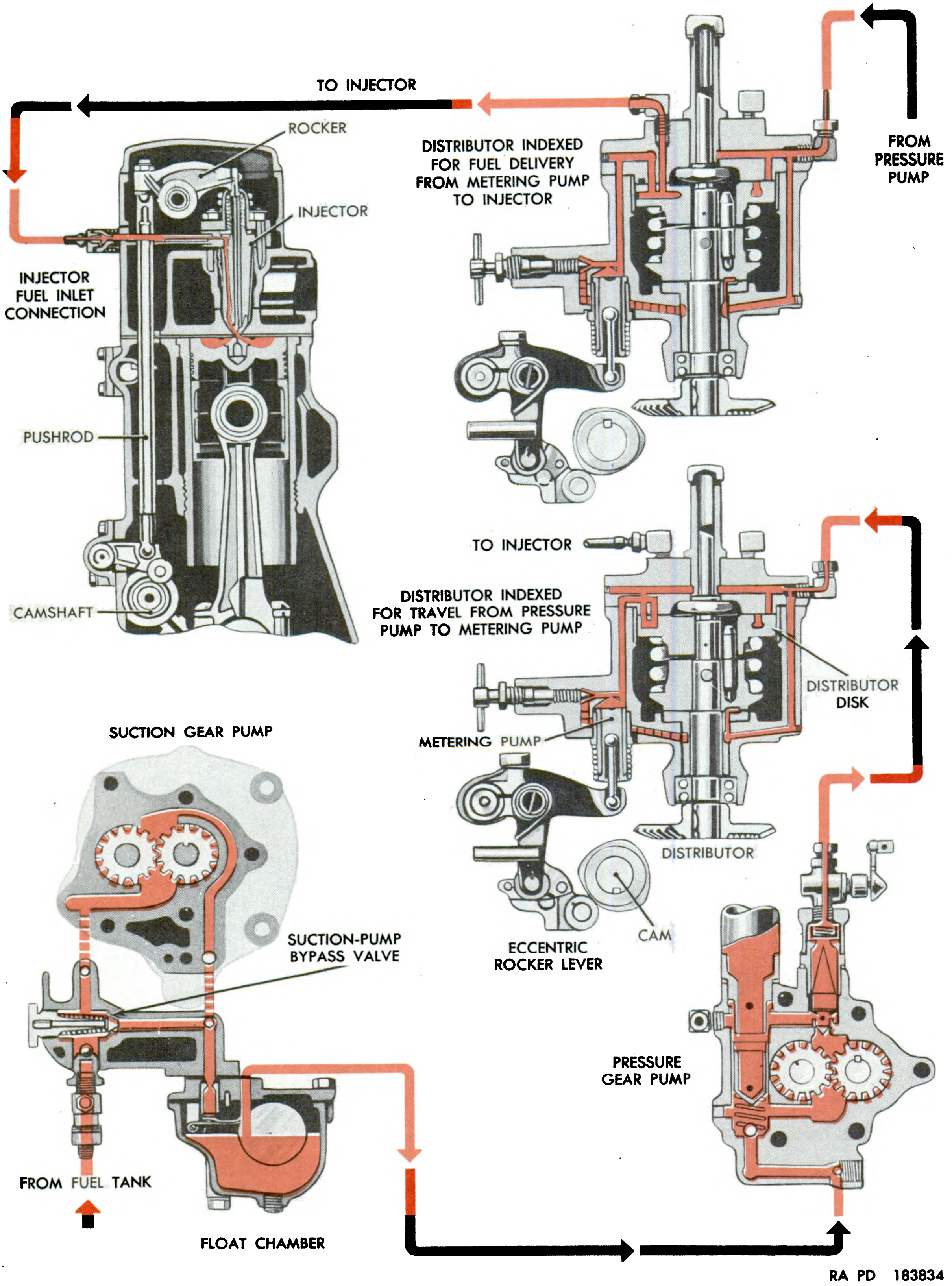

TO INJECTOR
ROCKER
INJECTOR
INJECTOR FUEL INLET CONNECTION
PUSHROD
CAMSHAFT
DISTRIBUTOR INDEXED FOR FUEL DELIVERY FROM METERING PUMP TO INJECTOR
FROM PRESSURE PUMP
TO INJECTOR
DISTRIBUTOR INDEXED FOR TRAVEL FROM PRESSURE PUMP TO METERING PUMP
DISTRIBUTOR DISK
METERING PUMP
DISTRIBUTOR
ECCENTRIC ROCKER LEVER
CAM
SUCTION GEAR PUMP
SUCTION-PUMP BYPASS VALVE
FROM FUEL TANK
FLOAT CHAMBER
PRESSURE GEAR PUMP
RA PD 183834

Figure 113. Fuel flow in distributor type system.

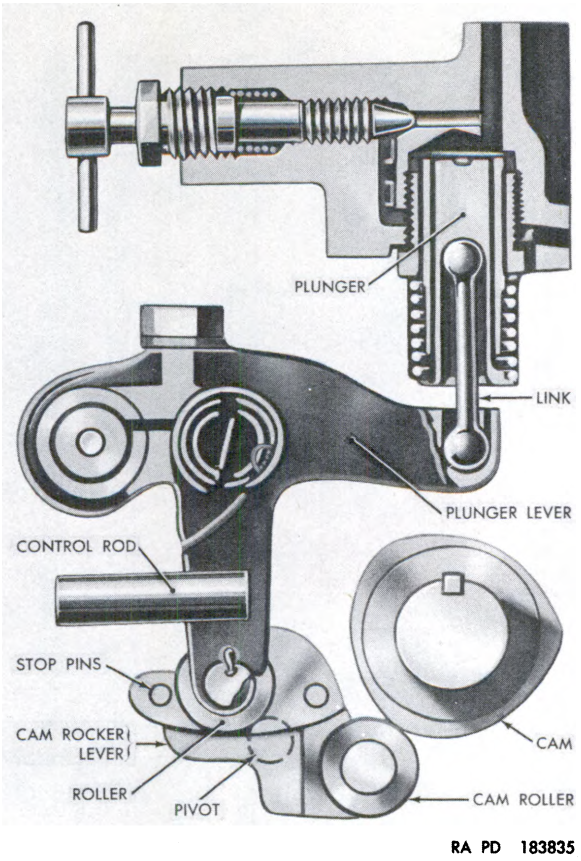


Figure 114. Variable stroke plunger for metering fuel.

is the cup which contains the nozzle tip. On the intake stroke of the engine, the fuel metering pump forces a charge of fuel of the exact amount of the load and speed of the engine into this cup. The operation of the metering pump requires that the fuel line and passage leading to the cup be filled with fuel (fig. 116A). It naturally follows that any fuel added at the fuel metering pump end will push the same amount of fuel into the injector cup. The fuel lies in the cup during the compression stroke of the engine, and the compressed air is forced through the small spray holes in the cup. The fuel oil in the tip of the cup is exposed to the intense heat and blasting of the compression, and, thus, is preheated and broken up (fig. 116B). A few degrees before top center, the plunger is forced down and the preheated fuel charge is driven out into the cylinder (fig. 116C) and the plunger ends its stroke. A small check valve is located in the lower end of the fuel passage in the injector body. This check valve prevents the compression pressures from blowing the fuel back and filling the lines with air.

79. Unit Injection System

The unit injection system consists of injectors, fuel supply pump, fuel oil filters, and the fuel oil manifolds. Fuel is drawn from the supply tank through the primary filter by the fuel supply pump. From the pump, fuel is forced through the secondary filter and to the fuel intake manifold which supplies the injectors. Surplus fuel, flowing through the injectors, is returned through the fuel outlet manifold to the supply tank.

a. Injector Mounting. Unit injectors (fig. 117) combine the injection pump, the fuel valves, and the nozzle in a single housing to eliminate the high-pressure lines. These units provide a complete and independent injection system for each cylinder and are mounted in the cylinder head, with their spray tips slightly below the top of the inside surface of the combustion chambers. A clamp, bolted to the cylinder head and fitting into a machined recess in each side of the injector body, holds the injector in place in a water-cooled copper tube

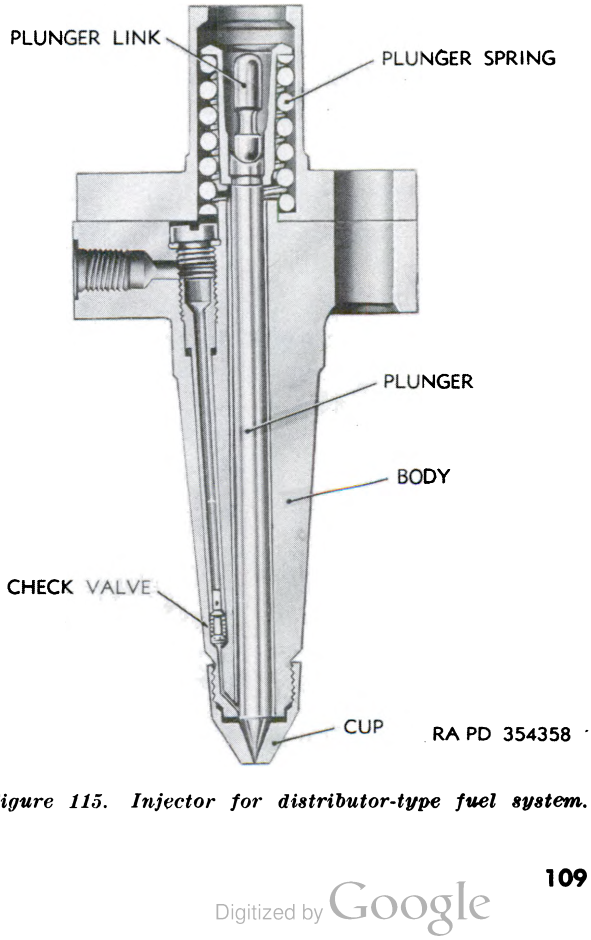


Figure 115. Injector for distributor-type fuel system.

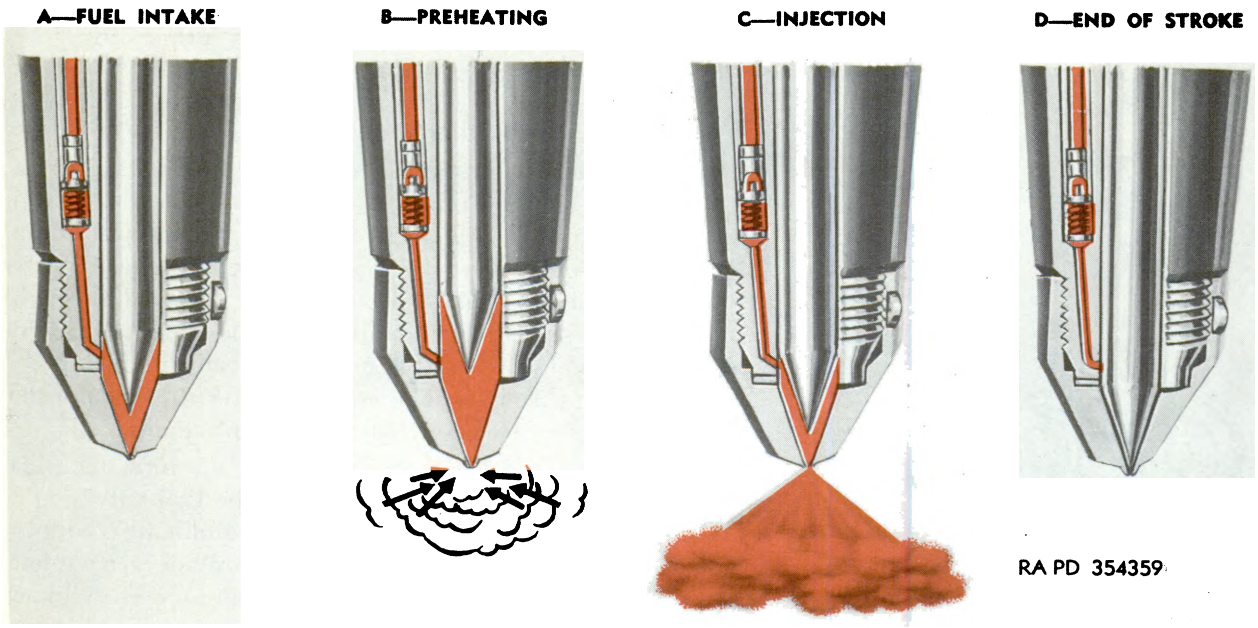


Figure 116. Four stages in fuel injection cycle.

which passes through the cylinder head. The tapered lower end of the injector seats in the copper tube, forming a tight seal to withstand the high pressures inside the cylinder.

b. Injector Operation.

(1) The cross section of a typical unit injector (fig. 118) shows the various parts. Fuel oil is supplied to the injector at a pressure of about 20 psi and enters the body at the top through the filter cap. After passing through the fine-grained filter element in the inlet passage, the fuel oil fills the annular (ring-shaped) supply chamber between the bushing and the spill deflector. The plunger operates up and down in this bushing, the bore of which is connected to the fuel supply in the annular chamber by two funnel-shaped ports, one on each side at different heights.

(2) The injector rocker arms (fig. 117) are actuated through push rods from the engine camshaft. The motion of the injector rocker arm is transmitted to the plunger by the follower, which bears against the return spring. In addition to this reciprocating motion, the plunger can be rotated in operation around its axis by the gear, which is in mesh with the control rack. Each injector control rack is connected by an easily detachable joint to a lever on a common control tube which, in turn, is linked to the governor and throttle. For metering purposes, a recess with an upper helix and a lower helix or a straight cutoff is machined into the lower end of the plunger. The relation of this upper helix and lower cutoff to the two ports changes with the rotation of the plunger. As the plunger moves downward, the fuel oil in the high-pressure cylinder or bushing is first displaced through the ports back into the supply chamber until the lower edge of the plunger closes the lower port. The remaining oil is then forced upward through the center passage in the plunger into the recess between the upper helix and the lower cutoff, from which it can flow back into the supply chamber until the helix closes the upper port. The rotation of the plunger, by changing the position of the helix, retards or advances the closing of the ports and the beginning and ending of the injection period, at the same time, increasing or de-

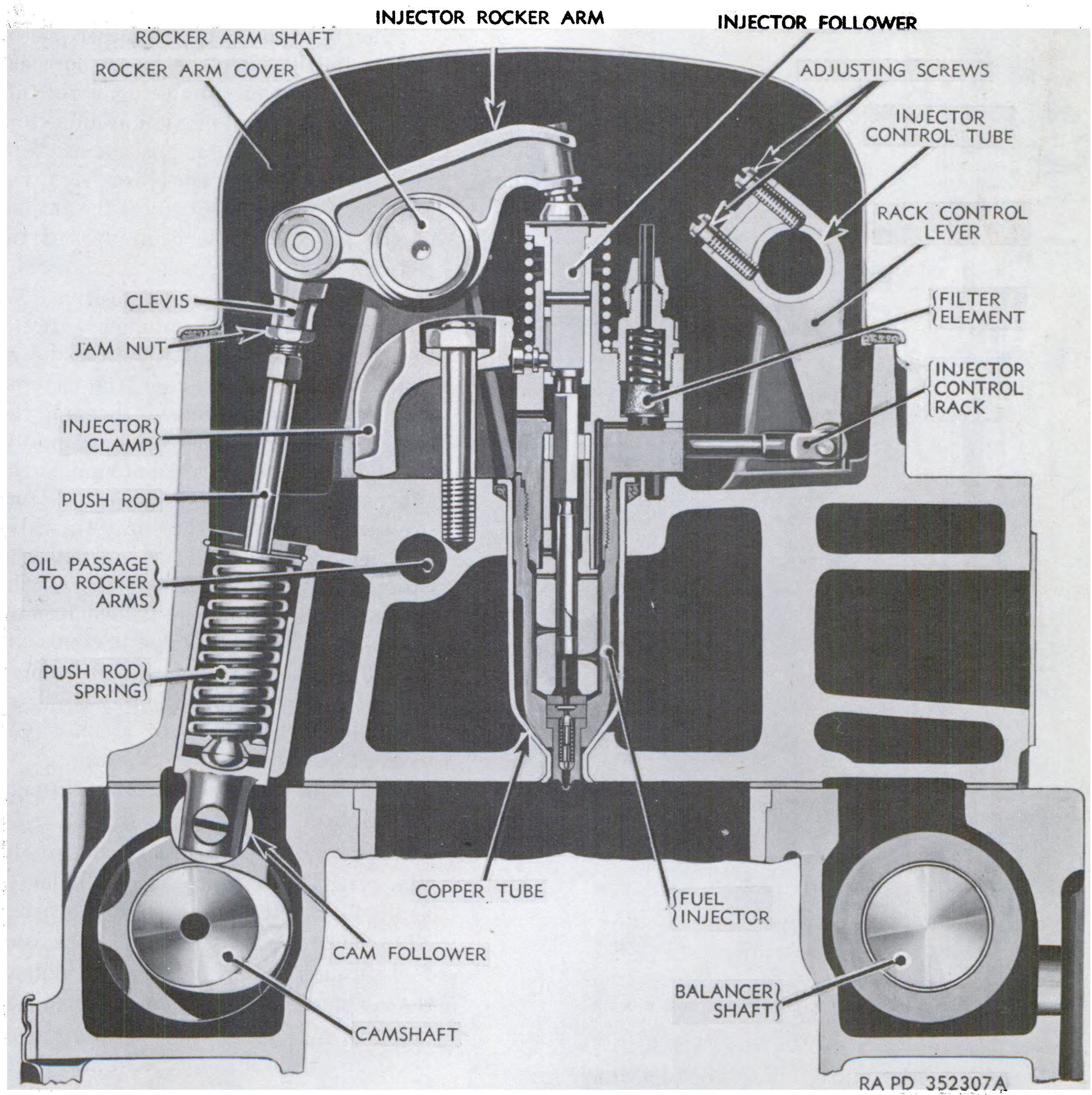

INJECTOR ROCKER ARM
INJECTOR FOLLOWER
ROCKER ARM SHAFT
ROCKER ARM COVER
ADJUSTING SCREWS
INJECTOR CONTROL TUBE
RACK CONTROL LEVER
CLEVIS
FILTER ELEMENT
JAM NUT
INJECTOR CONTROL RACK
INJECTOR CLAMP
PUSH ROD
OIL PASSAGE TO ROCKER ARMS
PUSH ROD SPRING
COPPER TUBE
FUEL INJECTOR
CAM FOLLOWER
BALANCER SHAFT
CAMSHAFT
RA PD 352307A

Figure 117. Single-unit fuel injector mounted in cylinder head.

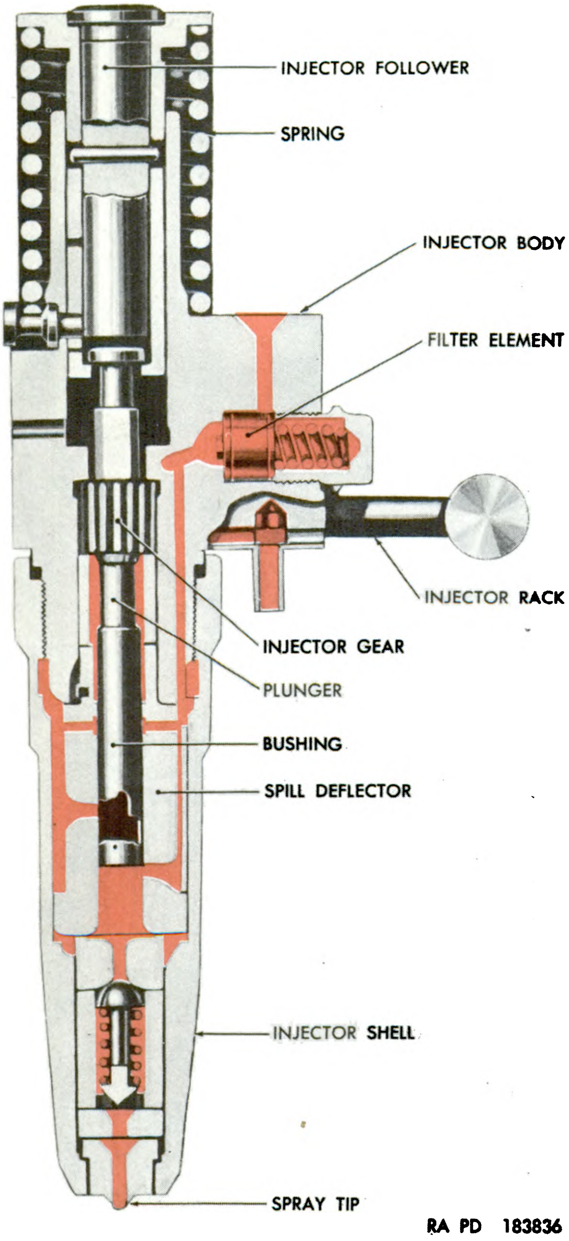


Figure 118. United injector—cross sectional view.

creasing the desired amount of fuel which remains under the plunger for injection into the cylinder.

(3) Figure 119 shows the various plunger positions from "NO-INJECTION" to "FULL-LOAD." With the control rack pulled out completely (no-injection), the upper port is not closed by the helix until after the lower port is uncovered. With the control rack in this position, all the fuel charge is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed in completely (full-load), the upper port is closed shortly after the lower port has been covered, thus producing a full effective stroke and maximum injection. From the no-injection position to full-load position (full rack movement), the contour of the helix advances the closing of the ports and the beginning of injection.

(4) Figure 120 shows various positions for downward travel of the plunger with the rack in a fixed position. On the downward travel of the plunger, the metered amount of fuel is forced through the center passage of the valve assembly, through the check valve, and against the spray-tip valve. When sufficient fuel pressure is built up, the spray-tip valve is forced off its seat and fuel is discharged through several small orifices in the spraytip and atomized in the combustion chamber. The check valve prevents air leakage from the combustion chamber into the fuel system if the spray-tip valve is accidently held open by a small particle of dirt, allowing the injector to operate until the particle works through the valve.

(5) On the return upward movement of the plunger, the high-pressure cylinder is again filled with oil through the ports. The constant circulation of fresh cool fuel through the injectors, which renews the surplus fuel supply in the chamber, helps to maintain even operating temperature of the injectors, and also effectively removes all traces of air which might otherwise accumulate in the system. The amount of fuel circulated through the injector is in excess of maximum needs, thus insuring sufficient fuel for all conditions.

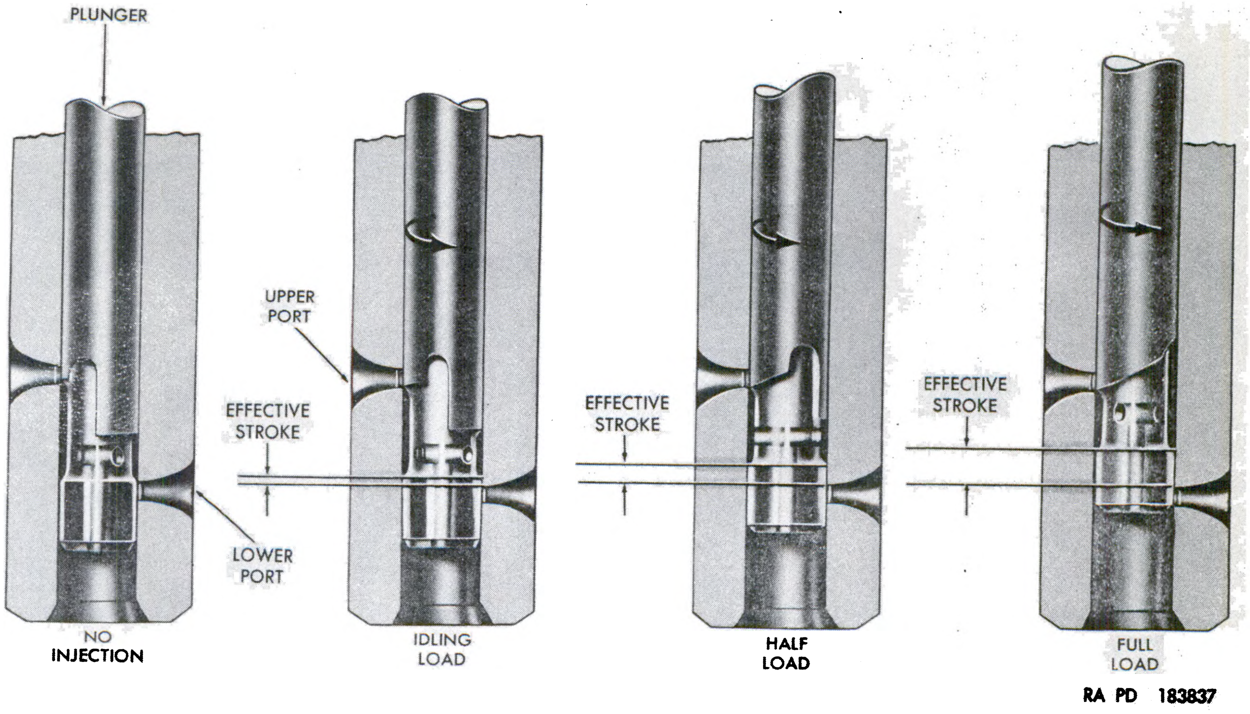

PLUNGER
UPPER PORT
EFFECTIVE STROKE
LOWER PORT
EFFECTIVE STROKE
EFFECTIVE STROKE
NO INJECTION
IDLING LOAD
HALF LOAD
FULL LOAD
RA PD 183837

Figure 119. Plunger positions from no-injection to full-load injection.

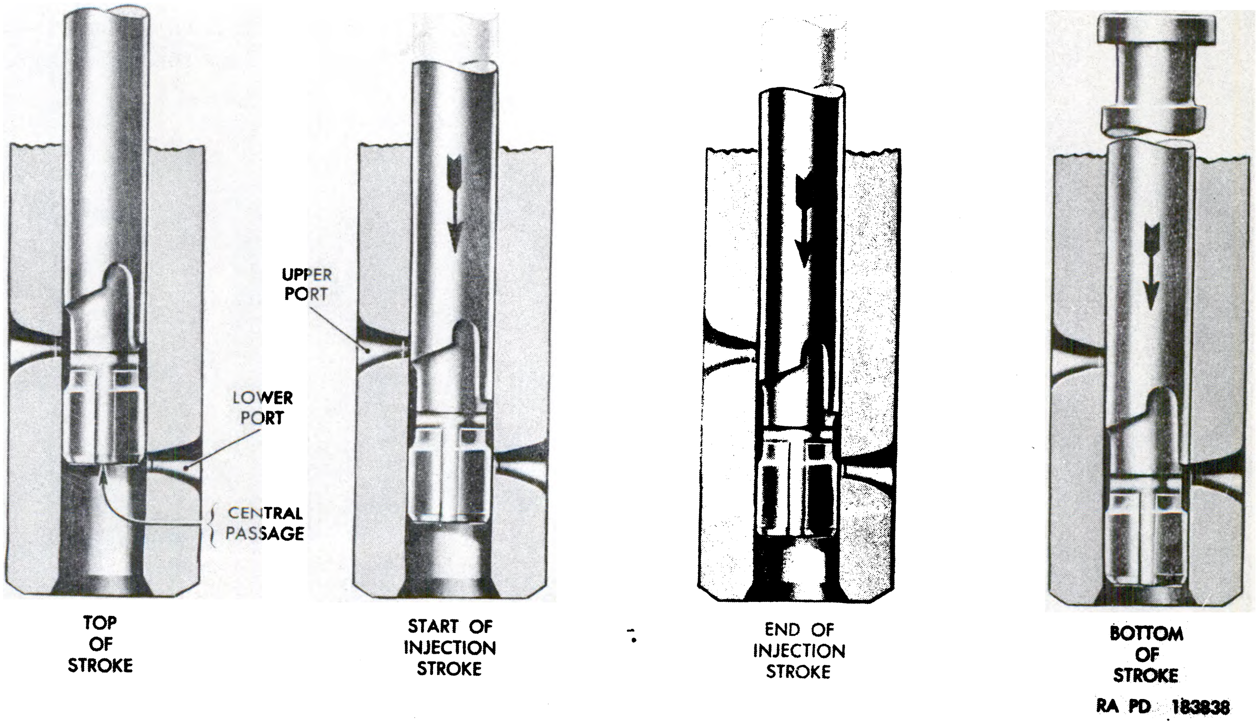
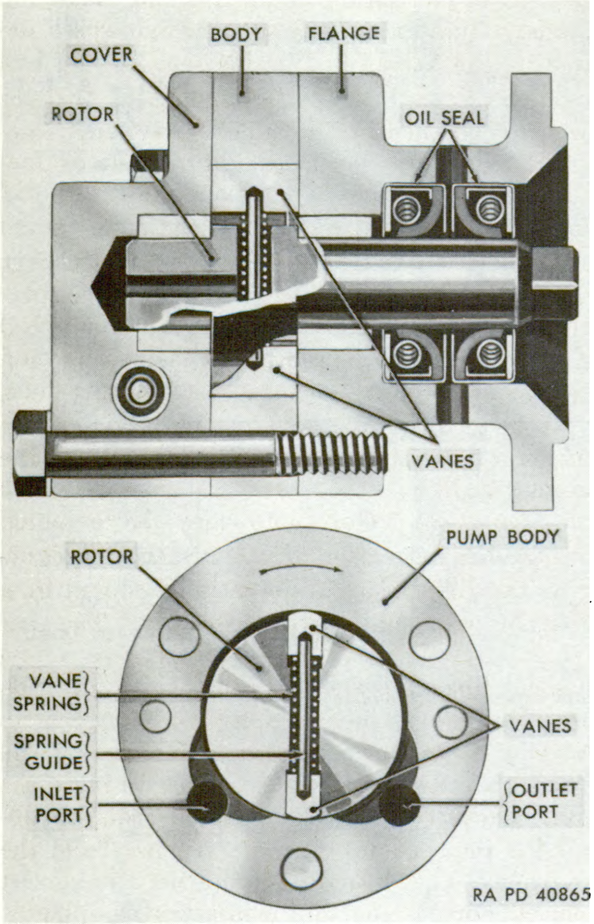

UPPER PORT
LOWER PORT
CENTRAL PASSAGE
TOP OF STROKE
START OF INJECTION STROKE
END OF INJECTION STROKE
BOTTOM OF STROKE
RA PD 183838

Figure 120. Four positions of injector during downward travel.

Section III. FUEL SUPPLY UNITS



COVER
BODY
FLANGE
ROTOR
OIL SEAL
VANES
ROTOR
PUMP BODY
VANE SPRING
SPRING GUIDE
INLET PORT
VANES
OUTLET PORT
RA PD 40865

Figure 121. Vane-type fuel supply pump.

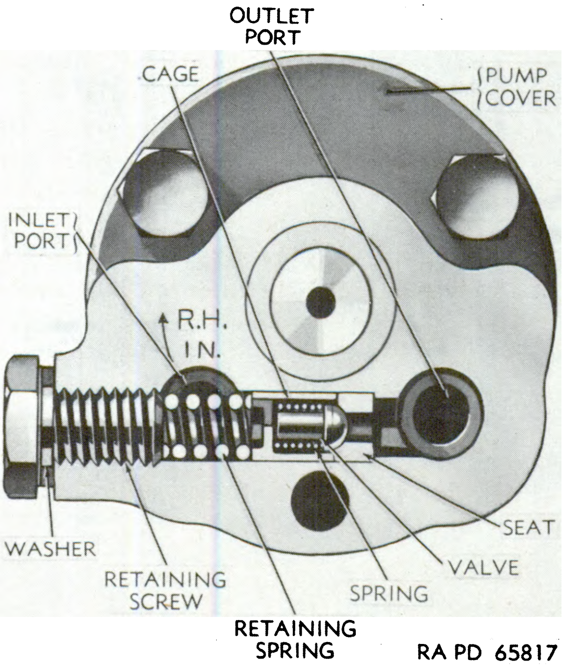
80. Fuel Supply Pumps

a. Types. Fuel injection pumps must be supplied with fuel oil under pressure because they have insufficient suction ability. Therefore, all injection systems require supply pumps to transfer fuel from the supply tanks to the injection pumps. Pumps used for this purpose have a positive suction lift, and their performance is largely independent of any reasonable variations in viscosity, pressure, or temperature of the fuel. The pumps in use today are of the gear, plunger, or vane types. The gear type is similar in operation to the pump used in the lubrication system (par. 101), hence the discussion of supply pumps in this paragraph will be limited to the vane and plunger types.

b. Vane Type.

(1) The fuel oil pump shown in figures 121 and 122 is a vane type. An integral steel rotor and shaft, one end supported in the pump flange and the other end in the cover, revolves in the body, the bore of which is eccentric to the rotor. Two sliding vanes are placed 180° apart in slots in the rotor and are pressed against the body bore by springs in the slots. Two oil seals on the pump shaft prevent leakage of fuel or lubricating oil. A drain hole between the two seals leads to the atmosphere.

(2) When the shaft is rotated, the vanes pick up fuel at the inlet port and carry it around the body to the outlet side, where the fuel is discharged. Pressure is produced by the wedging action of the fuel as it is forced toward the outlet port by the vane. A spring-loaded horizontal relief valve is provided in the cover of the pump, connecting the inlet and outlet ports, and opens at a pressure of approximately 55 psi. This valve does not normally open, since its purpose is to relieve excessive pump pressure if any of the fuel lines or filters become plugged and build up an extremely high pressure in the pump. When the valve opens,



OUTLET PORT
CAGE
PUMP COVER
INLET PORT
R.H. IN.
WASHER
RETAINING SCREW
RETAINING SPRING
SPRING
VALVE
SEAT
RA PD 65817

Figure 122. Fuel supply pump relief valve.

fuel passes from the discharge side (pressure side) to the suction side of the pump.

c. Plunger Type.

(1) *Description.* The type of pump shown in figure 123 is usually mounted directly on the housing of the injection pump and is driven by the injection pump camshaft. It is a variable-stroke self-regulating plunger-type pump that will build pressure only up to a predetermined point.

(2) *Operation.* As the injection pump cam allows the plunger to be forced by its spring toward the camshaft, the suction effect created opens the inlet valve and permits the fuel to enter the plunger spring chamber. As the cam lobe drives the plunger against its spring, the fuel is forced by the plunger through the outlet valve and around into the chamber created in back of the plunger by its forward movement. As the injection pump cam continues to rotate, it allows the plunger spring (which is now under compression) to press the plunger backward again, forcing the fuel oil behind the plunger out into the fuel line leading to the filters and injection pump. At the same time, the plunger is again creating a suction effect, which allows additional fuel to flow through the inlet valve into the spring chamber. This pumping action continues as long as the fuel is being used by the injection pump fast enough to keep the supply pressure from rising to the point where it equals the force exerted by the spring on the plunger. The pressure between the supply pump and the injection pump holds the plunger stationary against the spring and away from the rod. This prevents further pumping action until the pressure drops enough to permit the plunger to resume operation. This entire cycle is automatic and continues as long as the engine is running.

81. Governors

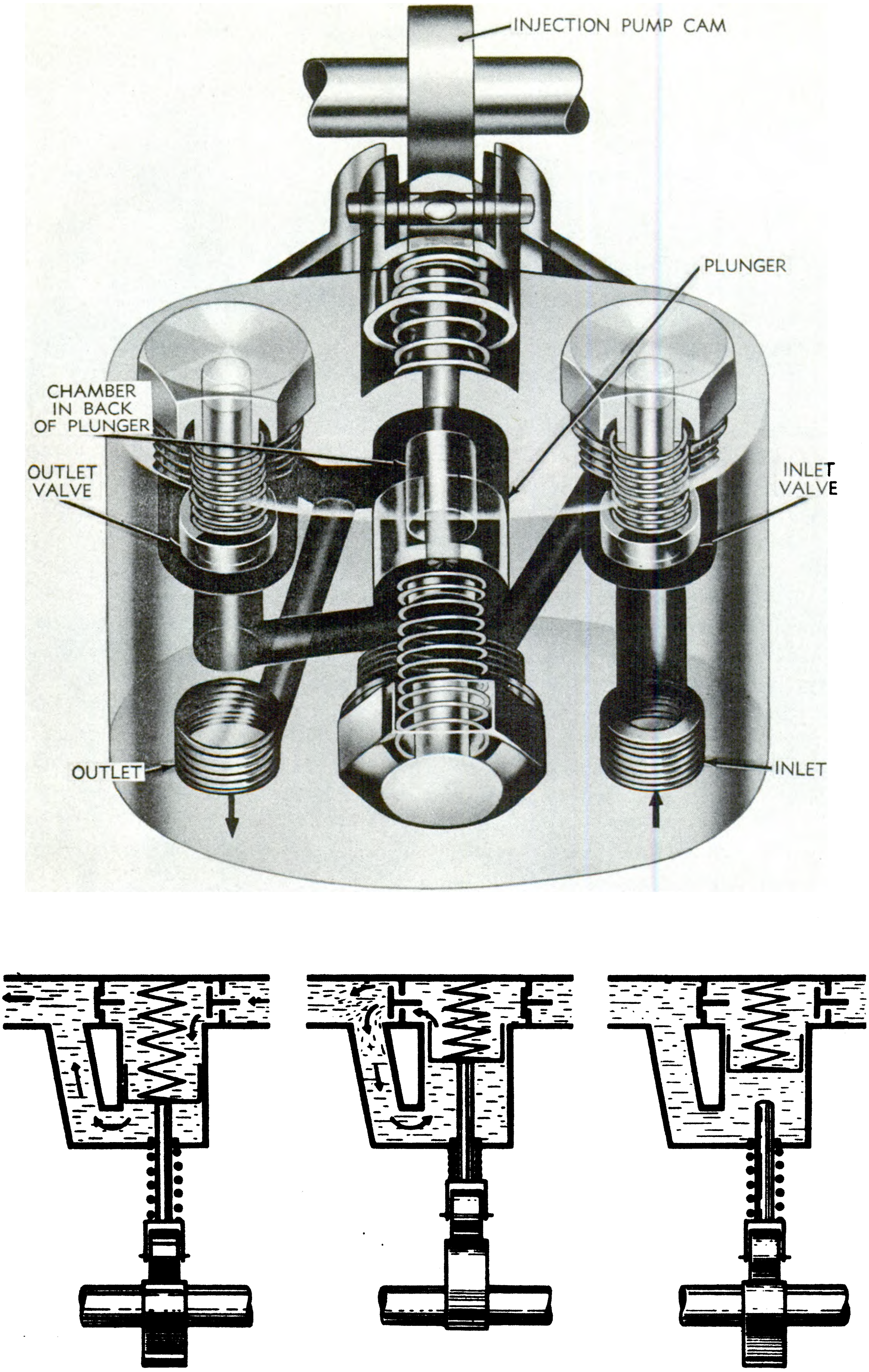
a. Types. All diesel engines require governors to prevent overspeeding of the engines under light loads. Automotive diesel engines also demand control of the idling speed. Any of the installations provide a variable-speed control which, in addition to controlling minimum and maximum speeds, will maintain any intermediate speed desired by the operator. Engine speed in a diesel engine is controlled by the amount of fuel injected; consequently, the injection system is designed to supply the maximum amount of fuel which will enable the engine to operate at full load and reach a predetermined maximum speed (rpm). However, if the maximum fuel charge was supplied to the cylinders with the engine operating under "PARTIAL LOAD" or "NO LOAD," the engine speed would increase beyond the critical range and soon cause a failure. Thus, it can be seen that the governor must control the amount of fuel injected in order to control the engine speed.

b. Actuation. Governors may be actuated through the movement of centrifugal flyweights or by the air-pressure differential produced by a governor valve and venturi assembly. The centrifugal flyweight type may incorporate a mechanical linkage system to control the injection pump, or it may include a hydraulic system to transmit the action of the weights to the pump. Where the rate of acceleration must be high, the governor-controlling weights must be small to obtain the required rapidity of response from the governor. These small weights may not exert sufficient force to control the injection equipment; instead, the injection pump will be controlled by a servo piston utilizing pressure from a pump within the governor. The centrifugal weights actuate a valve which controls the amount of oil going to the servo piston.

c. Mechanical (Centrifugal).

(1) The operation of the mechanical governor is based on the centrifugal force of rotating weights counterbalanced by springs. When the speed of the engine increases, the weights fly outward, pulling with them suitable linkage to change the setting of the injection pump control rod. The governor linkage is connected to the injection pump in such a manner that the spring moves the control mechanism toward the full-fuel position, and the action of the flyweights reduces the the amount of fuel delivered.

(2) A typical variable speed governor is shown schematically in figures 124 and 125. With this type of governor, the op-


INJECTION PUMP CAM
PLUNGER
CHAMBER IN BACK OF PLUNGER
OUTLET VALVE
INLET VALVE
OUTLET
INLET

RA PD 354362

Figure 123. Plunger-type fuel supply pump.

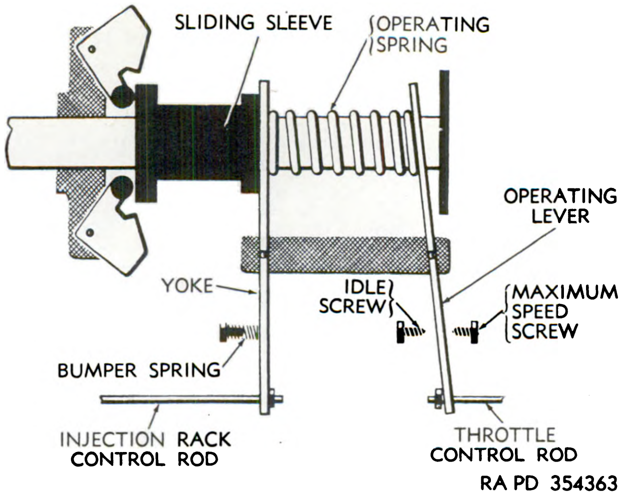

SLIDING SLEEVE
OPERATING SPRING
OPERATING LEVER
YOKE
IDLE SCREW
MAXIMUM SPEED SCREW
BUMPER SPRING
INJECTION RACK CONTROL ROD
THROTTLE CONTROL ROD
RA PD 354363

Figure 124. Variable speed governor.

erator varies the governor spring tension to control the quantity of fuel and does not at any time move the injector control rack directly. The control rack of the injection pump is connected to the yoke of the governor in such a manner that any movement of the yoke will directly affect the quantity of fuel injected. The spring tension is controlled by the operating lever, the movement of which is determined by the position of the foot throttle. The travel of the operating lever is limited by the idle- and maximum-speed screws. With the weights fully collapsed (engine stopped), the spring moves the sliding sleeve and yoke so the fuel injection pump is in the full-fuel position. When the weights are fully extended, the sliding sleeve and yoke move to the right and decrease the amount of fuel delivered.

(3) If the load on the engine is decreased, the engine tends to accelerate. However, when the engine accelerates, the governor flyweights move outward as a result of increased centrifugal force. Since the flyweights are in contact with the sliding sleeve assembly, this movement causes a longitudinal movement of the sleeve to the right. This movement continues until an equilibrium is established between the governor spring force and the centrifugal force exerted by the flyweights. This occurs when the engine returns to the original speed, as determined by the position of the foot throttle and its effect on the governor spring.

(4) If the load on the engine increases, the engine tends to slow down, thereby causing an inward movement of the flyweights. As the weights move inward, resulting in reduced force on the sliding sleeve, the compressed governor spring shifts the sleeve to the left until the spring force and the centrifugal force exerted by the flyweights are again balanced. In this way, the yoke, following the movement of a sliding sleeve, moves the control rack of the fuel injection pump toward the more-fuel position and thereby returns the engine to the preset speed.

(5) To accelerate the vehicle, depress the foot throttle, which, in turn, increases the spring tension. This causes the yoke to pivot to the left, thereby increasing the supply of fuel. The flyweights move outward as a result of increased engine speed and prevent the control rack from reaching the full-fuel position unless the

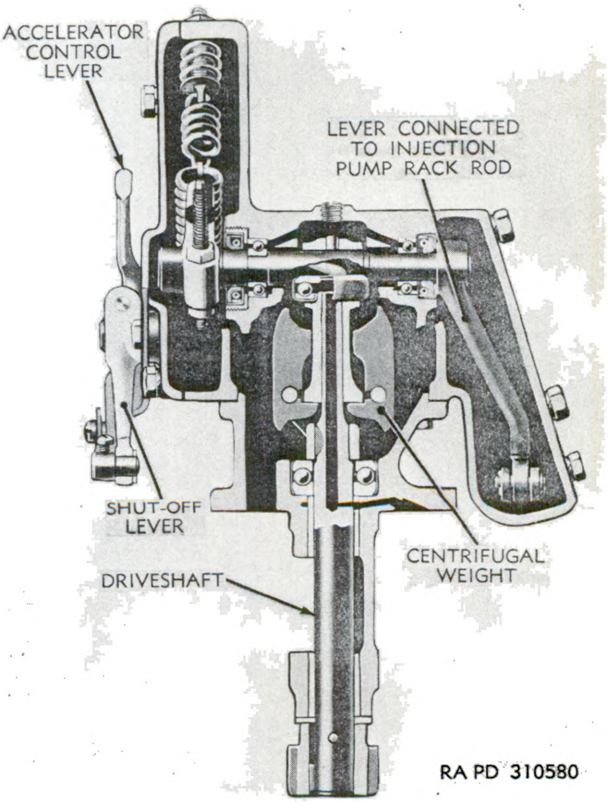

ACCELERATOR CONTROL LEVER
LEVER CONNECTED TO INJECTION PUMP RACK ROD
SHUT-OFF LEVER
DRIVESHAFT
CENTRIFUGAL WEIGHT
RA PD 310580

Figure 125. Variable speed governor.

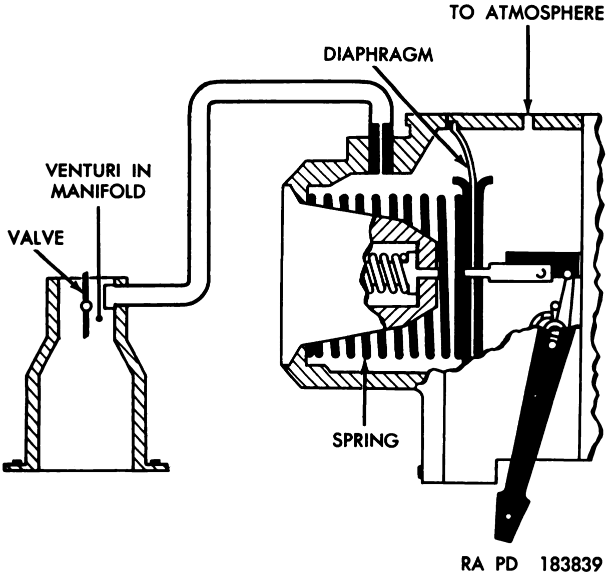


Figure 126. Pneumatic governor.

foot throttle is fully depressed. Deceleration is accomplished in the reverse manner. Spring pressure is decreased, the engine slows down, the flyweights move inward, and a balanced condition between the flyweights and the spring is obtained at a lower engine speed.

(6) The adjustable bumper spring prevents rapid oscillations of the control rack at low no-load engine speeds. The spring contacts the yoke at idling speed and insures steady operation of the governor. The bumper spring also assists in preventing stalling of the engine on sudden deceleration to idle speed, as it prevents the control rack of the injection pump from moving into the full-stop position when this speed change occurs.

d. Pneumatic.

(1) The actuating force for the pneumatic or vacuum-controlled governor is the pressure drop caused by the velocity of air passing through a venturi located in the air intake manifold (par. 44). The governor (fig. 126) consists essentially of an atmospheric-suspended diaphragm connected by linkage to the control rack of the fuel injection pump. The chamber on one side of the diaphragm is open to the atmosphere, and the chamber on the other side is sealed and connected to the venturi in the manifold. In addition, there is a spring acting on the sealed side of the chamber, which moves the diaphragm and control rack to the full-fuel position when the engine is not operating and both sides of the diaphragm are at atmospheric pressure. When the engine is running, however, the pressure in the sealed chamber is reduced below the atmospheric pressure existing in the other chamber. The amount of pressure reduction depends on the position of the governor valve and the speed of the engine. It is this pressure differential that positions the diaphragm and consequently, the control rack. The governor valve is controlled by a lever which is connected by suitable linkage to the foot throttle. There is no actual connection between the foot throttle and the governor or fuel injection pump.

(2) If the engine is operating under load and the speed (rpm) is below governed speed, the velocity of air passing through the venturi is comparatively low and only a slight pressure differential is present. The spring moves the diaphragm and control rack toward the full-fuel position, and the engine speed approaches that of governed speed. The same principle prevents the engine from overspeeding at light loads. As the engine speeds up, the velocity of air through the venturi increases, with the result that the pressure differential at the diaphragm is increased. This differential is sufficient to overcome the spring force and to cause the diaphragm and control rack to move toward the STOP position. When the engine is operating at governed speed with the valve wide open, the pressure differential is just slightly below that of the spring force, and the diaphragm remains in the full-delivery position.

(3) For any position of the governor valve between idling and full load of the engine, the diaphragm finds its relative position. Since any movement of the diaphragm is also transmitted to the control rack, the amount of fuel delivery is definitely controlled at all engine speeds. As the pressure drop between the chambers is increased, the diaphragm is moved

in the direction of less fuel delivery. As the pressure drop is decreased, the spring can move the control rack in the direction of greater fuel delivery. Therefore, in order to increase the speed of the engine, the governor valve is opened; to decrease the engine speed, the valve is closed.

82. Fuel Filters

a. Thorough and careful filtration is especially necessary to keep diesel engines efficient. Diesel fuels are more viscous than gasoline. They contain more gums and more abrasive particles, which may cause premature wear of the injection equipment. The abrasives may consist of material difficult to eliminate during the process of refining, or they may enter the fuel tank through careless refueling. Whatever the source, it is imperative that means be provided to protect the system from these abrasives.

b. Most diesel engine designs include at least two filters in the fuel supply systems to protect the closely fitted parts in the pumps and nozzles. The primary (coarser) filter is usually located between the supply tank and the fuel supply pump. The secondary (finer) filter is found between the fuel supply pump and the injection pump. Additional filtering elements are frequently installed between the injection pump and the nozzle.

c. Diesel fuel oil filters are referred to as *full-flow filters*, since all the fuel must pass through the filters before reaching the injection pumps. Filters must be inspected regularly and cleaned or replaced if maximum efficiency is to be maintained. All metal-disk filters and some cloth-bag-type filter elements are cleanable, but most cloth or fabric elements must be replaced when they become dirty. A diesel oil filter usually incorporates an air vent to release any air which might accumulate in the filter during operation.

d. Metal filters are used as primary filters because the fine particles that may pass through them are not as injurious to the supply pump as they would be to the injection pump. The filter illustrated in figure 127 is similar to the one described in paragraph 51*b* except that a cleaning knife is added. Solids larger than 0.005 inch remain on the outside of the element, and the cleaning knife serves to scrape these deposits off the filtering disks. The solids fall to the bottom of the filter housing where they can be removed through the drain plug hole. A ball relief valve in the filter cover enables the oil to bypass the filter element if the disks become clogged.

e. Fabric filters, because of their greater filtering qualities, are used principally as main filters for protecting the fuel injection pump. Many of the filters in use are similar to the lubricating oil filter described in paragraph 104; however, the bag-type filter (fig. 128) is more desirable because the element can be cleaned. The filtering medium is a large bag of close, evenly woven, lintless, acid-resisting textile material. Maximum benefit is derived from the bag's large area

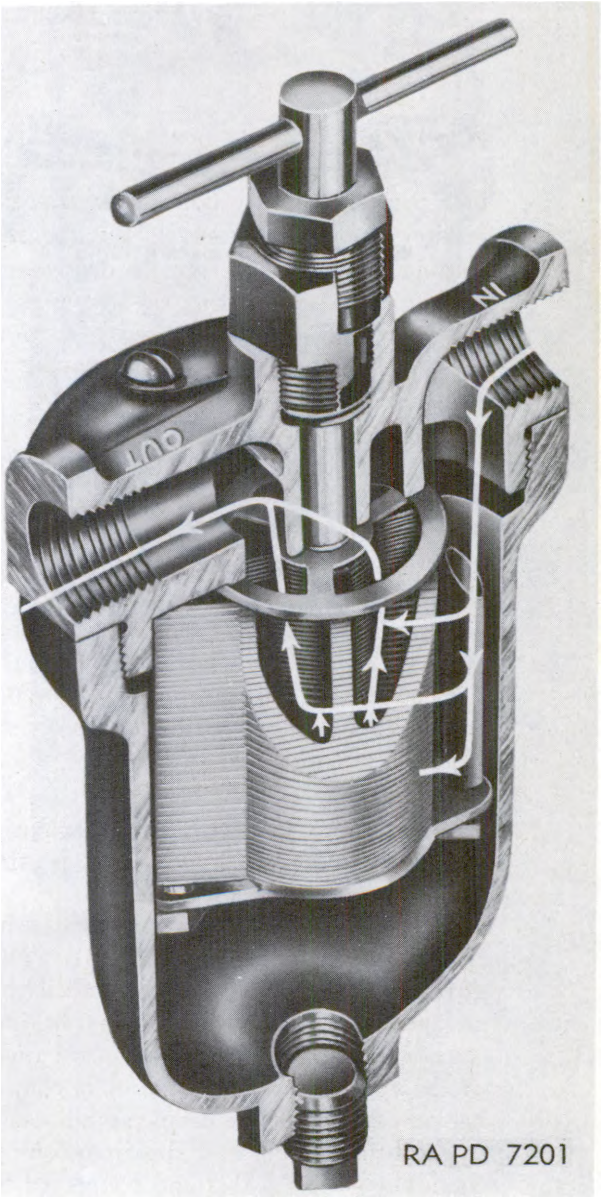
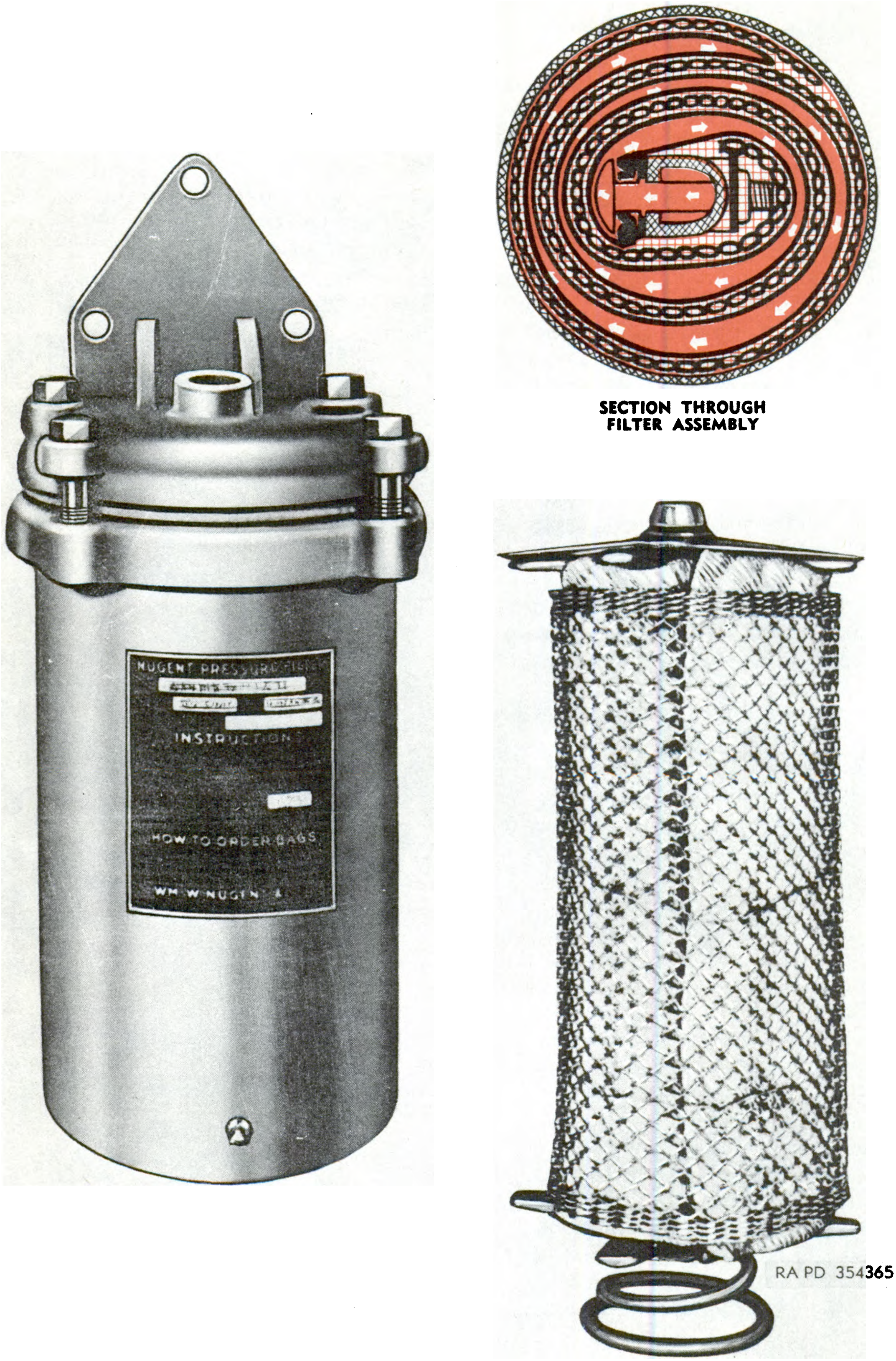


Figure 127. Metal filter.


NUGENT PRESSURE FILTER
INSTRUCTIONS
HOW TO ORDER BAGS
WM W NUGENT &

SECTION THROUGH FILTER ASSEMBLY

RA PD 354365

Figure 128. Cloth filter (bag type).

by keeping the sides of the bag separated by a wire-screen mat. The screen is the same size as the bag, and the two are detachably fastened to a central feeding spool and wound around it. Layers of bag and screen are thus alternated through the winding, and the entire surface of the bag is available for filtering purposes. The fuel to be filtered flows from the filter inlet at the top, through the spool, and out the ports to the inside of the bag. The dirt, solids, abrasives, carbon, etc., are caught in the bag, and the clean fuel passes outward and to the filter outlet. The bag may be turned inside out to expel the dirt, then washed and installed.

CHAPTER 7

COOLING SYSTEMS

Section 1. COOLING ESSENTIALS

83. Need for Cooling

All internal combustion engines are equipped with some type of cooling system because of the high temperatures they generate during operation. High temperature is necessary since it results in the high gas pressures which act on the head of the piston. Without high temperature, power cannot be produced efficiently. However, it is not possible to use all of the heat of combustion without producing harmful results. There is no accurate method of measuring the temperature in the combustion chamber during the burning of fuel, but it has been determined to be about twice the temperature at which iron melts. Therefore, if nothing is done to cool the engine during operation, valves will burn and warp, lubricating oil will break down, pistons and bearings will overheat, and pistons will seize in the cylinders.

a. Heat created by combustion must be dissipated by the cooling system. Other important, but often overlooked, mediums of cooling an internal combustion engine are the fuel and the lubricant. Cooling is not their primary purpose, but they nevertheless dissipate an appreciable amount of heat. Additional heat is lost through the exhaust. There must be careful control over the amount of heat dissipated because thermal efficiency is proportional to the operating temperature of the engine. For liquid-cooled engines, the ideal operating temperature is just below the boiling point of the coolant used if this temperature is not so high that it breaks down the lubricant.

b. Cooling systems usually are classified as liquid or air. Diesel and gasoline engine cooling systems are similar mechanically; however, the diesel runs cooler and it is not necessary that the capacity of its cooling system be as large as that of a gasoline engine. Diesel engines usually have the same size radiators as gasoline engines, but the speed and size of the fans are reduced.

84. Coolants

Water is the most widely used coolant for liquid-cooled engines. It should be clear and soft. Water is usually available, it costs practically nothing, and its boiling point falls within the range of efficient operating temperatures. The main objection to the use of water is that it has a high freezing point and cannot be used alone at temperatures below 32° F. Ethylene glycol is used in some liquid-cooled aircraft engines where the cooling system is sealed. Its advantages are that it does not evaporate in use, has a higher boiling point than water, does not require renewal unless lost through leakage, and requires less radiator area to obtain the same degree of cooling that water gives.

85. Additives

a. When a vehicle is operated where the atmospheric temperatures fall below 32° F., an antifreeze solution must be added if water is used as the cooling liquid. The four solutions in common use are methyl alcohol, ethyl alcohol, glycerin, and ethylene glycol. The first two, prepared commercially as antifreeze, are the cheapest and provide adequate protection when used in sufficient quantities. The main objection to them is that they boil and evaporate if normal operating temperature is exceeded. Glycerin offers the same degree of protection as alcohol and does not evaporate in use because it has a high boiling point. Ethylene glycol (antifreeze compound) has an extremely high boiling point (330° F.), does not evaporate in use, is noncorrosive, has no odor, and gives complete protection when used in the proper amount. The maximum protection from freezing is obtained from a solution of 40 percent water and 60 percent ethylene glycol antifreeze compound. This mixture gives protection at temperatures as low as −65° F. A higher concentration of ethylene glycol antifreeze compound will only raise the freezing point of the solution. If 100 percent ethylene glycol antifreeze compound is used, the freezing point is not much below that of water. Other antifreeze solutions, however, do not show this increase of freezing point with increasing concentration. For instance, methyl alcohol freezes at −144° F., while ethyl alcohol freezes at −174° F.

b. The cooling system must be free of rust and scale in order to maintain its efficiency. The use of inhibitors or rust preventatives will reduce or prevent corrosion and the formation of scale. Inhibitors are not cleaners and do not remove rust or scale already formed; they are merely added to the cooling liquid to arrest further rust or corrosion. Most commercial antifreeze solutions contain an inhibitor. If water alone is used as the coolant, an inhibitor should be added.

86. Flow of the Coolant

A simple liquid cooling system consists of a radiator, coolant pump, piping, fan, thermostat, and a system of jackets and passages in the cylinder head and cylinder block through which the coolant circulates. Some engines are equipped with a water distribution tube inside the cooling passages that directs additional coolant to the points where temperatures are highest. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The pump draws the coolant from the bottom of the radiator, forces it through the jackets and passages, and ejects it into the upper tank on top of the radiator (fig. 129). The coolant passes through a set of tubes to the bottom of the radiator and again is circulated through the engine by the action of the pump. A fan draws air over the outside of the tubes in the radiator and cools the liquid as it flows downward. It should be noted that the liquid is pumped through the radiator from the top down. The reason for this direction of flow is that thermosiphon action aids the pump to circulate the coolant. This simply means that as the coolant is heated in the jackets of the engine, it expands, becomes lighter, and flows upward to the top of the radiator. As cooling then takes place in the radiator tubes, the coolant contracts, becomes heavier, and sinks to the bottom. This desirable thermosiphon action cannot take place if the level of the coolant is permitted to become low.

Section II. LIQUID COOLING SYSTEMS

87. Engine Water Jacket

a. The water passages in the cylinder block and cylinder head form the engine water jacket (fig. 129). In the cylinder block, the water jacket completely surrounds all cylinders along their full length. Within the jacket, narrow water passages are provided between cylinders for coolant circulation. In addition, water passages are provided around the valve seats and other hot parts of the cylinder block.

b. In the cylinder head, the water jacket covers the combustion chambers at the top of the cylinders and contains water passages around the valve seats when they are located in the head. The coolant flows from the cylinder block up into the cylinder head through passages called *water transfer ports.* A tight seal at the ports between the cylinder head and block is very important. The watertight seal at the ports, as well as the gastight seal at the combustion-chamber openings, is obtained with one large gasket called the *cylinder-head gasket.* It has two functions to perform: it must seal the extreme pressures of combustion within the cylinders and, at the same time, maintain a tight seal in the coolant joints at the water transfer ports.

88. Radiator

Radiators for automotive vehicles using liquid-cooling systems consist of two tanks (fig. 129) with a core between them to form the radiating element. The upper tank contains an outside pipe called the *radiator inlet* and usually has a coolant baffle inside and above or at the inlet opening. The radiator filler neck is generally attached to the upper part of the upper tank and has an outlet to the overflow pipe. The lower tank also has a pipe opening (radiator outlet).

a. The upper tank collects incoming coolant and distributes it across the top of the radiator core. The baffle in the tank assists in distributing the coolant to the water tubes and also prevents cool-

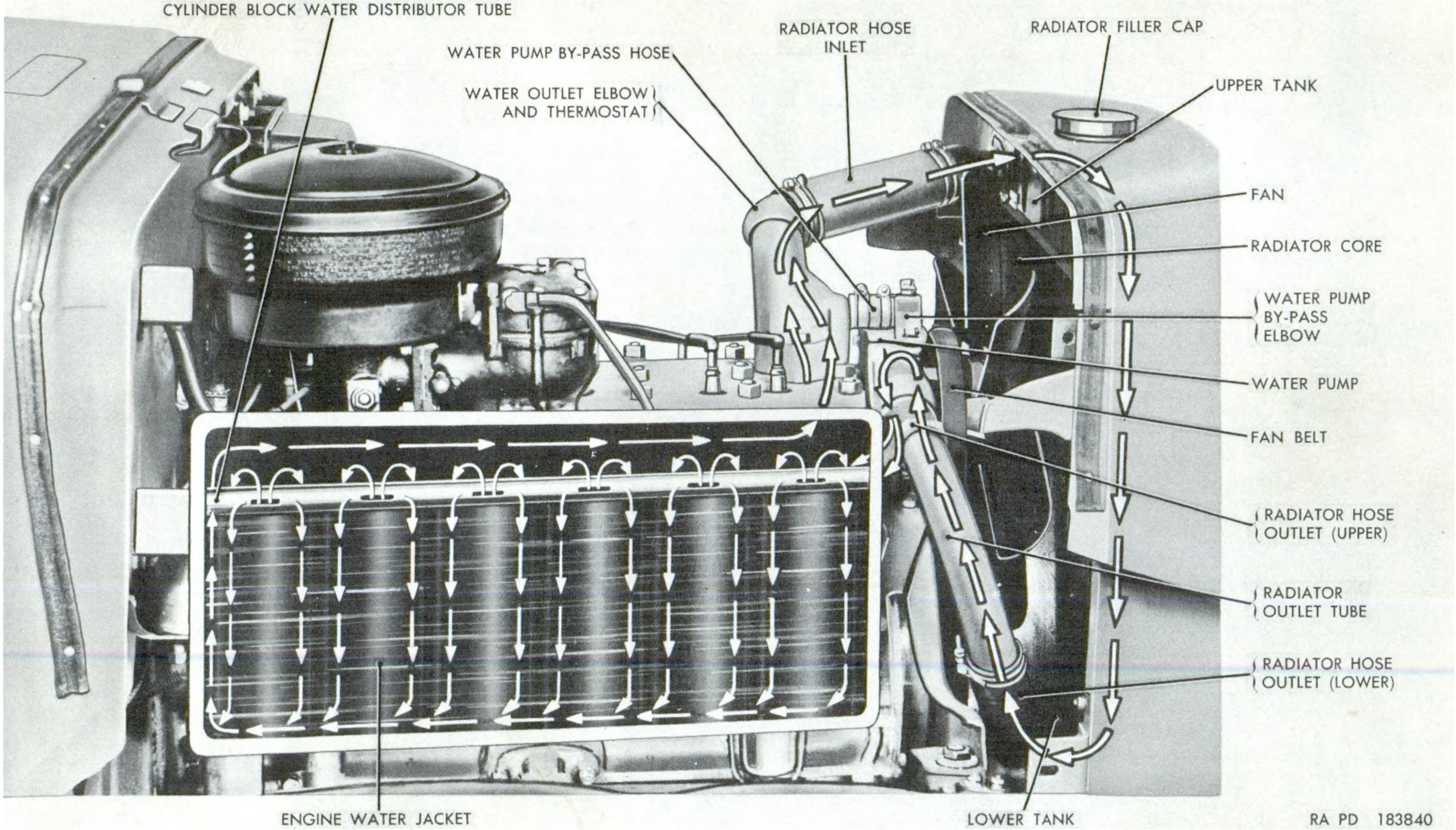

CYLINDER BLOCK WATER DISTRIBUTOR TUBE
WATER PUMP BY-PASS HOSE
WATER OUTLET ELBOW AND THERMOSTAT
RADIATOR HOSE INLET
RADIATOR FILLER CAP
UPPER TANK
FAN
RADIATOR CORE
WATER PUMP BY-PASS ELBOW
WATER PUMP
FAN BELT
RADIATOR HOSE OUTLET (UPPER)
RADIATOR OUTLET TUBE
RADIATOR HOSE OUTLET (LOWER)
ENGINE WATER JACKET
LOWER TANK
RA PD 183840

Figure 129. Cooling system circulation.

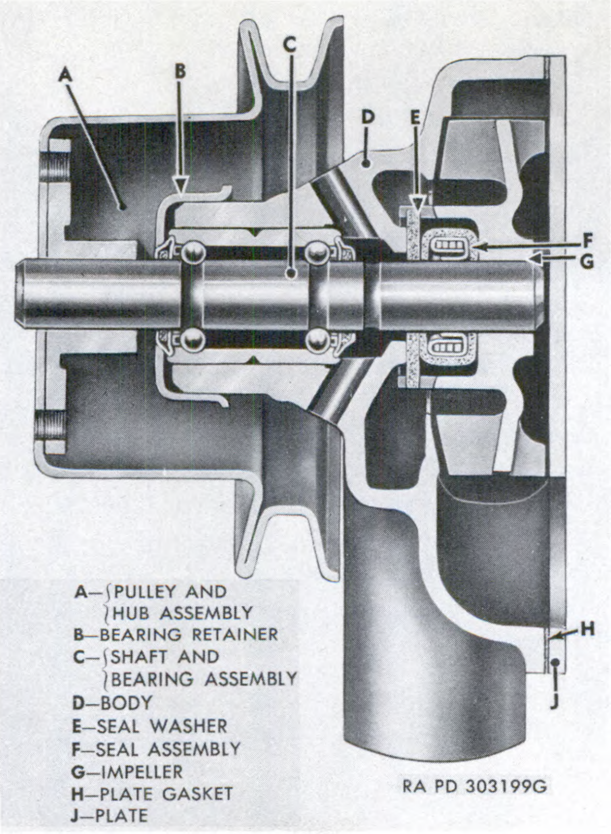


Figure 130. Water pump.

ant from being thrown out of the radiator. The overflow pipe provides an opening from the radiator for escape of coolant or steam that otherwise might cause excessive pressure, which would rupture the thin metal walls of the radiator. The lower tank collects coolant flowing from the core and discharges it through the radiator outlet.

b. Some liquid-cooling systems have tubular radiator cores which consist of a large number of vertical water tubes and many horizontal air fins around the tubes. Water passages in the tubes are narrow, and the tubes are made of thin metal. The core divides the coolant into very thin columns or ribbons, thus exposing a large radiating surface to the volume of liquid to be cooled.

89. Water Pump

All modern cooling systems have water pumps to circulate the coolant. The pump (fig. 130), usually located on the front or side of the engine block, receives coolant from the lower tank and forces it through the water jacket into the upper tank. The pump is a centrifugal type and has an impeller with blades, which force the coolant outward as the impeller rotates. The pump and fan usually are driven from a common V-belt which is driven by a pulley at the front end of the crankshaft. Advantages of the centrifugal pump are that it is inexpensive, circulates great quantities of liquid for its size, and is not clogged easily by small particles of dirt. Another advantage is that it permits limited circulation by thermosiphon action even if the engine is not running.

90. Fan and Shroud

The fan circulates a large volume of air through the radiator core. In addition to removing heat from the radiator, this flow of air also provides some direct air cooling of the engine. Military vehicles are often equipped with a funnel-like structure (shroud) (fig. 131) around and behind the fan. The shroud directs the flow of air for most effective cooling.

91. Thermostat

The water pump starts the coolant circulating through the system as soon as the engine is started, no matter how low the temperature, so a thermo-

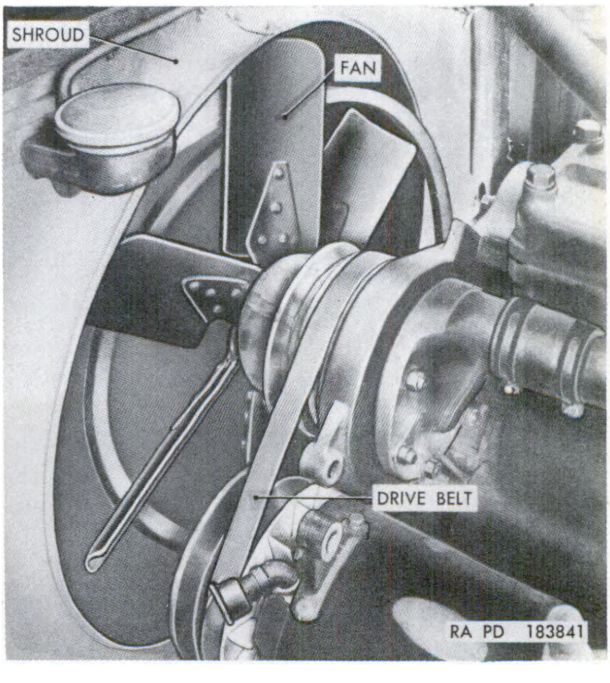


Figure 131. Cooling fan, drive belt, and shroud.

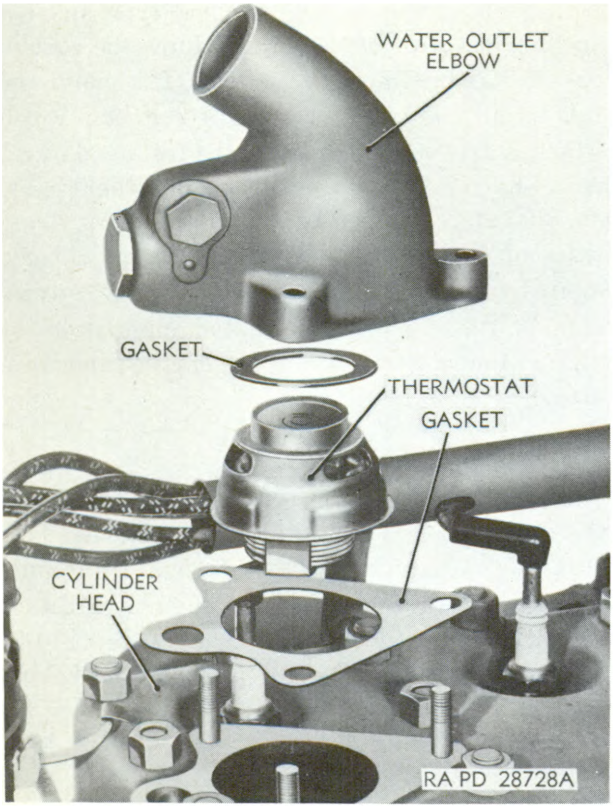


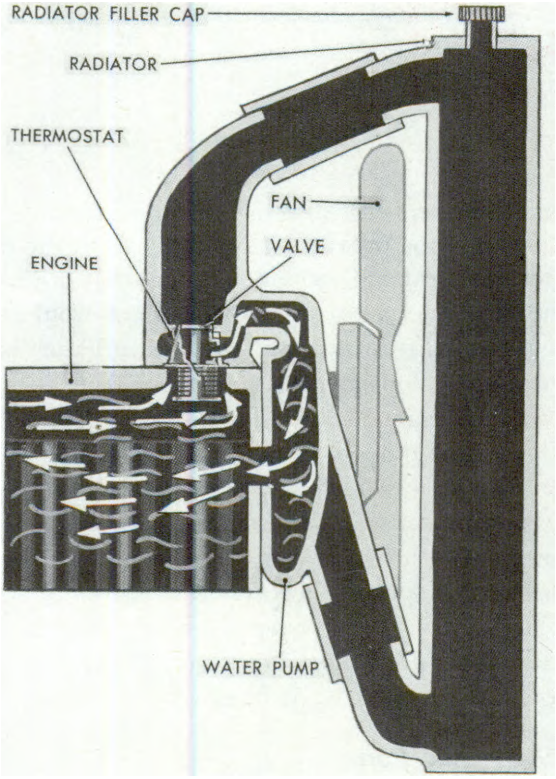
Figure 132. Thermostat.

stat must be installed to insure quick warmup and to prevent overcooling in cold weather. A thermostat regulates engine temperature by automatically controlling the amount of coolant flowing from the engine block to the radiator core.

a. The thermostat is merely a heat-operated unit which controls a valve between the water jacket and the radiator. A typical thermostat (fig. 132) consists of a flexible-metal bellows attached to a valve. The sealed bellows, which is expandable, is filled with a highly volatile liquid such as ether. When the liquid is cold, the bellows chamber is contracted and the valve is closed (fig. 133). When heated, the liquid is vaporized and expands the chamber. As the chamber expands, the valve opens (fig. 134). When the engine is cold, the thermostat is closed and the coolant is recirculated through the water jacket without entering the radiator. As the engine warms up, the valve slowly opens and some of the coolant begins to flow through the radiator, where it is cooled. Other types include a sealed copper bellows containing only air; another is bimetallic and for its operation depends upon the difference in cofficients of expansion of the two metals.

b. The thermostat is located between the water jacket and the radiator, usually in the housing of the cylinder-head-water-outlet elbow (fig. 129). It is constructed so that, if it fails to function properly, it will fail in the open position, allowing free circulation of water through the engine.

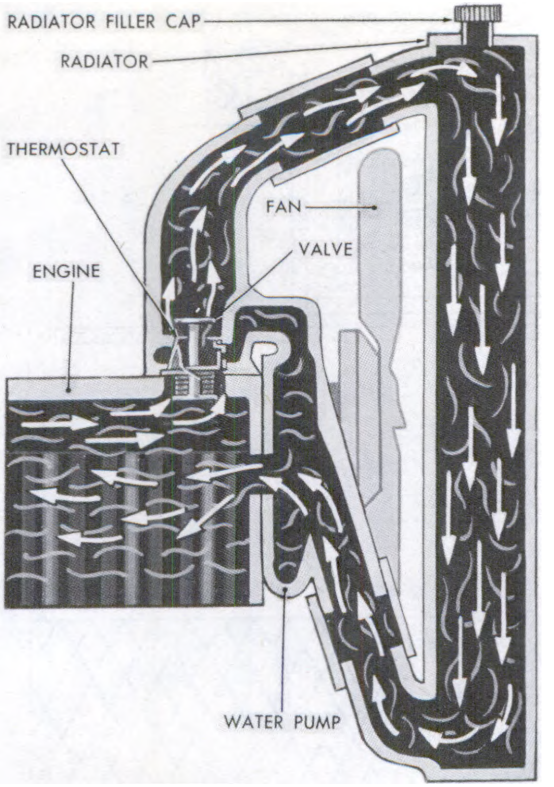
c. Some military vehicles are equipped with air inlet screens or shutters. They have no direct connection with the cooling system and are primarily for protection. However, they may be used to supplement or replace the action of a thermostat, and are operated either by hand or automatically by a thermostatic device. The shutters restrict the flow of cool air through the radiator when the coolant is below a predetermined temperature. When the coolant reaches the proper temperature, the shutters start to open.



ENGINE COLD—VALVE CLOSED BY THERMOSTAT ALLOWS WATER TO CIRCULATE THROUGH THE ENGINE BUT NOT THE RADIATOR

RA PD 183842

Figure 133. Thermostat closed.



ENGINE WARM—VALVE OPENED BY THERMOSTAT ALLOWS WATER TO CIRCULATE THROUGH THE ENGINE AND THE RADIATOR

RA PD 183843

Figure 134. Thermostat open.

92. Pressure Radiator Cap

Some cooling systems are sealed and use a pressure radiator cap (figs. 135 and 136) to close off the overflow-pipe opening. If the overflow pipe were open, the surging movement of the coolant as the vehicle moved would allow some of the coolant to overflow into the pipe and be lost. The pressure cap serves to prevent overflow loss of coolant during normal operation. It also allows a certain amount of pressure to develop within the system, which raises the boiling point of the coolant and permits the engine to operate at higher temperatures without coolant overflow from boiling. The cap contains two spring-loaded valves, normally closed, which seal the system. The larger is the pressure valve and the smaller is the vacuum valve. The pressure valve acts as a safety valve to relieve extra pressure within the system; the vacuum valve opens only when the pressure within the cooling system drops below the outside air pressure as the engine cools off. Higher outside pressure then forces the vacuum valve to open, allowing air to enter the system by way of the overflow pipe.

93. Overflow Tank

When the cooling system is equipped with an overflow tank, the pressure cap is placed on the tank instead of on the radiator, and a plain cap is used on the radiator. Overflow, or surge, tanks are special equipment for operation in hot or dry country. The coolant expands as it is heated and contracts as it cools; consequently, the level of the coolant in the radiator is constantly changing as the engine operating temperature changes. This condition is further aggravated when the temperature becomes high enough to change the water to steam. The expansion is much greater and the pressure is also increased. The overflow tank makes it possible to keep the radiator full at all times. Overflow from the radiator, caused by the expansion or surging of steam vapor within the cooling system, passes through a tube to the overflow tank. The pressure cap on the overflow tank controls the pressure within the system in the same manner as described in paragraph 92. The plain cap on the radiator effectively seals the radiator opening so that the only vent to the atmosphere is through the cap on the overflow tank. When the coolant cools off, it contracts and the pressure in the upper part of the radiator drops below atmospheric. The pressure in the overflow tank, which is maintained above atmospheric by the pressure cap, forces the liquid to return to the radiator to be recirculated through the engine.

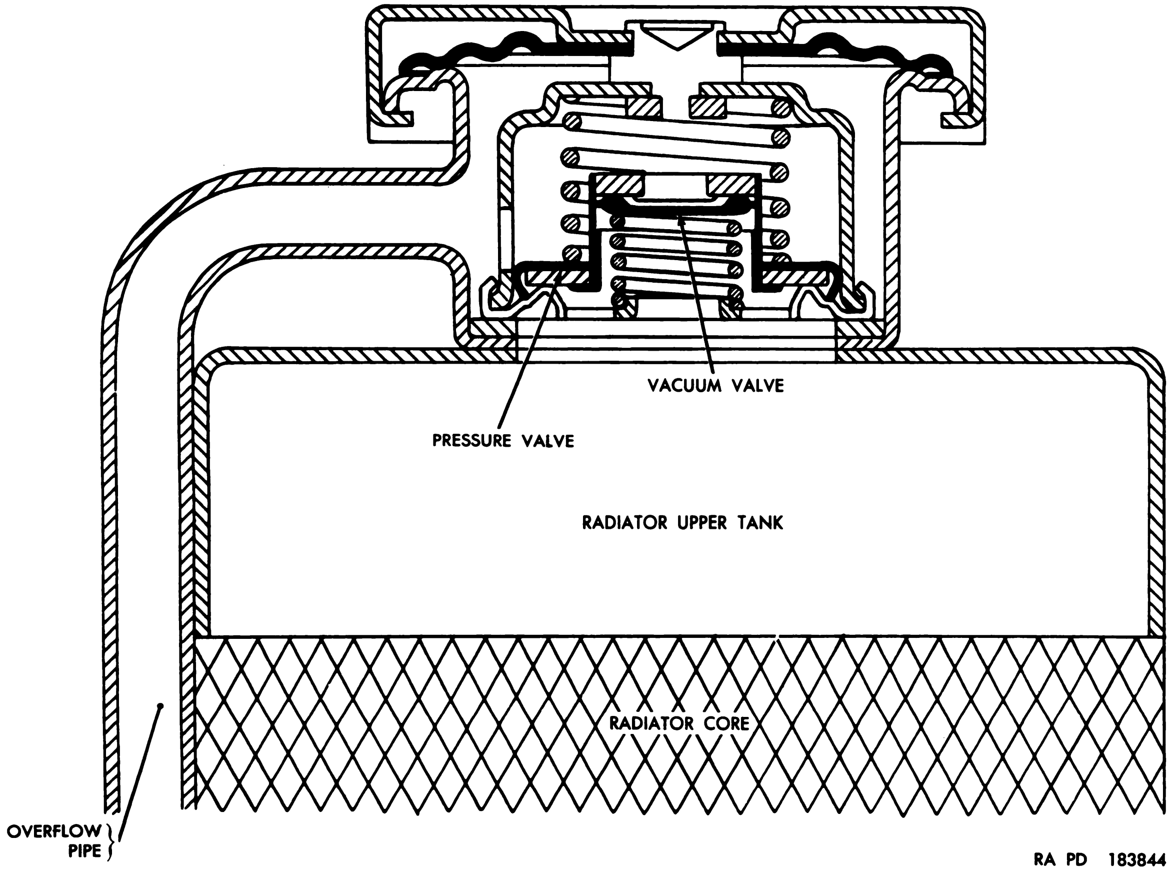

VACUUM VALVE
PRESSURE VALVE
RADIATOR UPPER TANK
RADIATOR CORE
OVERFLOW PIPE
RA PD 183844

Figure 135. Pressure radiator cap.

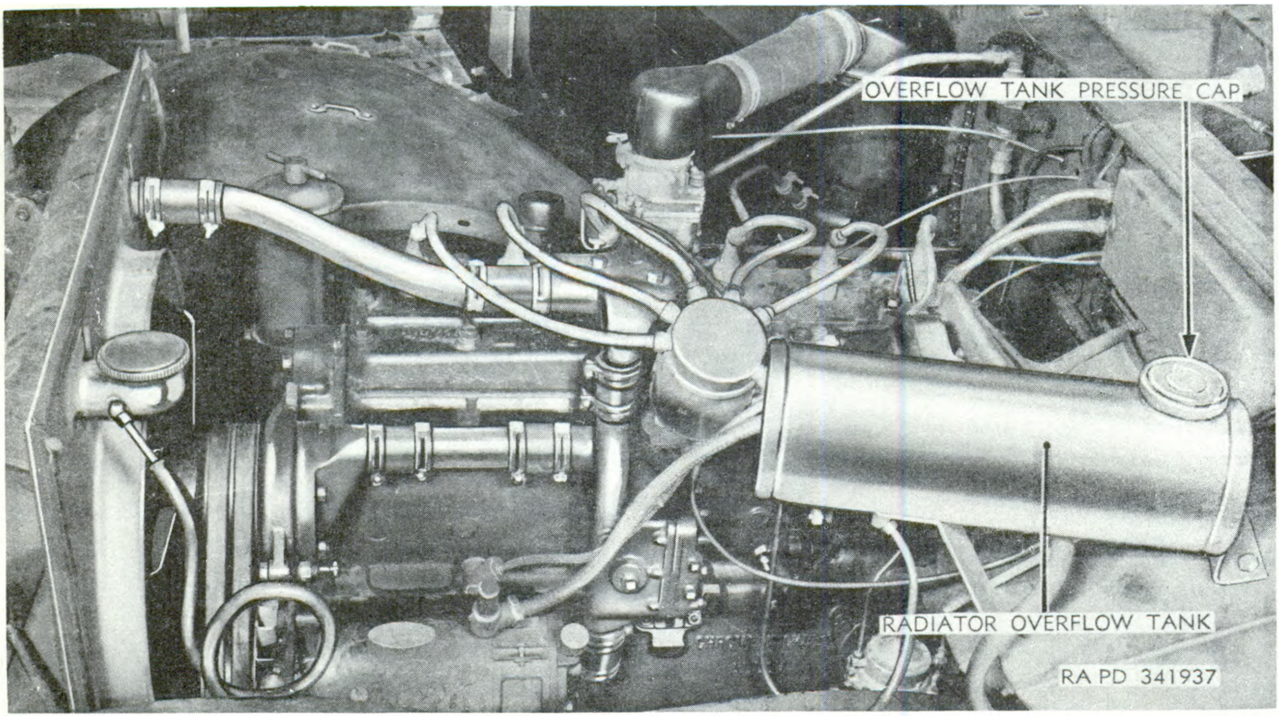

OVERFLOW TANK PRESSURE CAP
RADIATOR OVERFLOW TANK
RA PD 341937

Figure 136. Overflow tank and pressure cap.

Section III. AIR-COOLING SYSTEMS

94. General

Since an air-cooling system does not employ a liquid coolant, it is often assumed that air alone acts as the cooling medium. However, this is not true since, as was pointed out in paragraph 83, the fuel and lubrication systems also help in cooling the engine. The lubrication system for an air-cooled engine often includes an oil cooler which circulates the oil between the engine and the cooler, removing heat from the engine as it does so. Some cooling also results from the fuel contacting metal parts prior to combustion.

95. Construction

There are several physical characteristics peculiar to the automotive air-cooled engine; the cylinder head and barrel are heavily finned for strength and adequate cooling; and air deflectors, shrouds, or baffles direct the air flow to the cylinders and increase its velocity. Cooling fans are used to increase the volume of air circulating around the cylinders; this also increases the speed of the air passing the cylinders. In the radial engine, a ring-type cowling, or shroud, surrounds the engine as another means of directing the air flow to areas where it will do the most good; the cooling fan is mounted on the flywheel.

96. Principles

Construction of the parts mentioned in paragraph 95 embodies several fundamental principles of cooling: the rate of cooling is dependent upon the area exposed to the cooling medium, the heat conductivity of the metal used, the volume of metal or its size in cross section, the amount of air flowing over the heated surfaces, and the difference in temperature between the metal surfaces exposed and the cooling air.

97. Components, V-Type and Opposed-Cylinder Engines

a. Fans. V-type and opposed-cylinder air-cooled engines are very similar so far as the air-cooling systems are concerned. Figure 26 shows a 12-cylinder, V-type air-cooled engine with the shrouds and front fan removed. Figure 137 shows this same engine with both fans and the shrouds in place. The fans are driven by shafts and gears

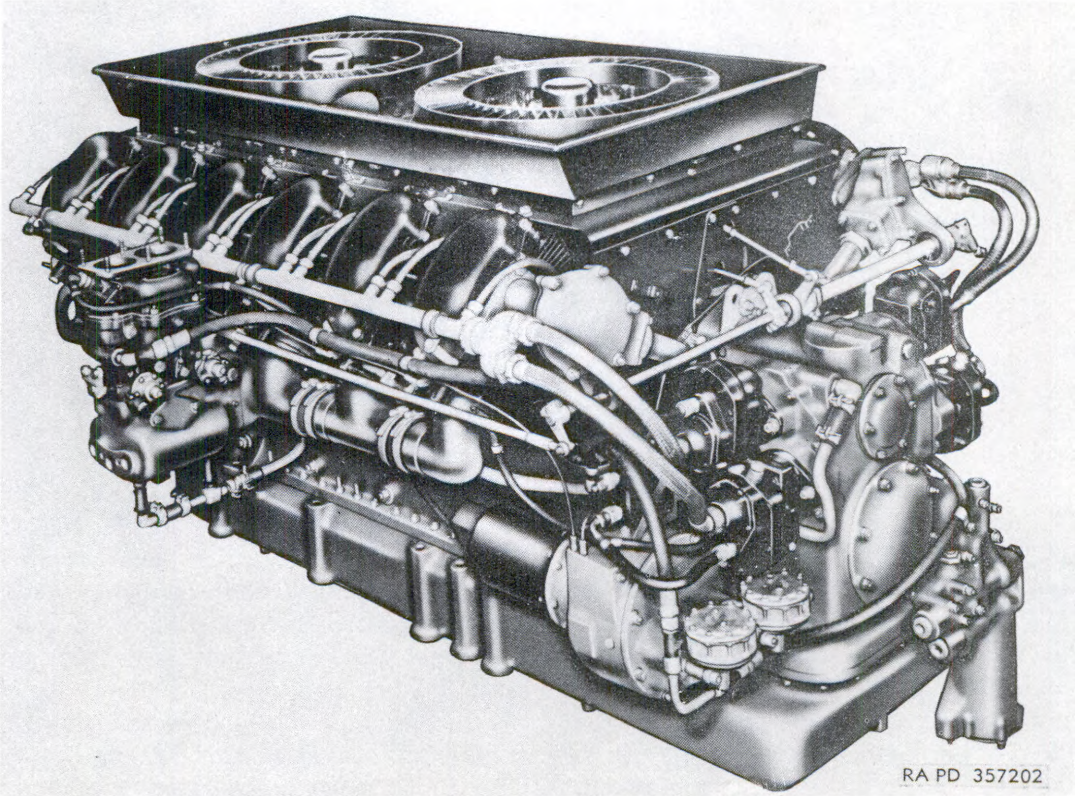


Figure 137. Air-cooled V–12 engine.

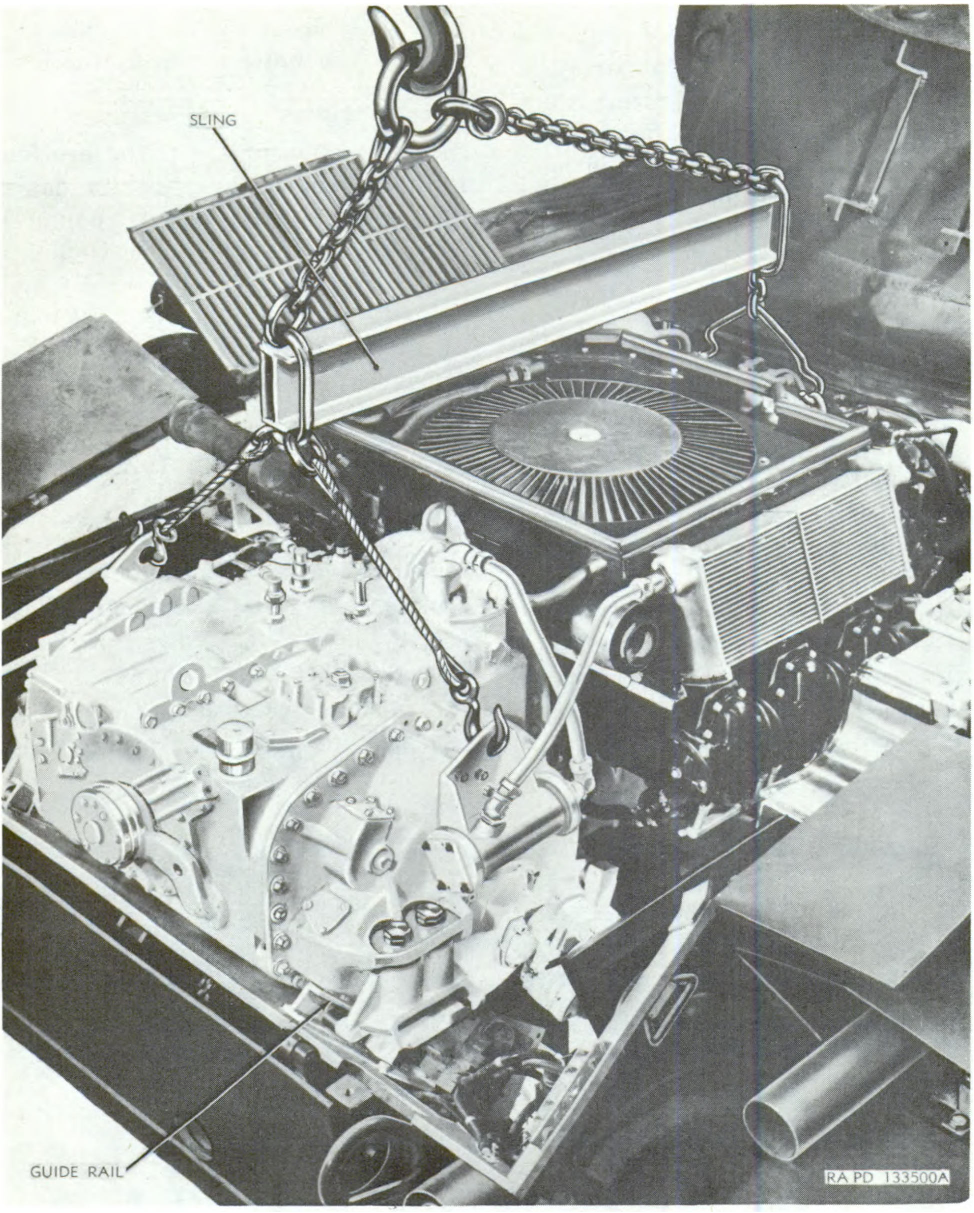
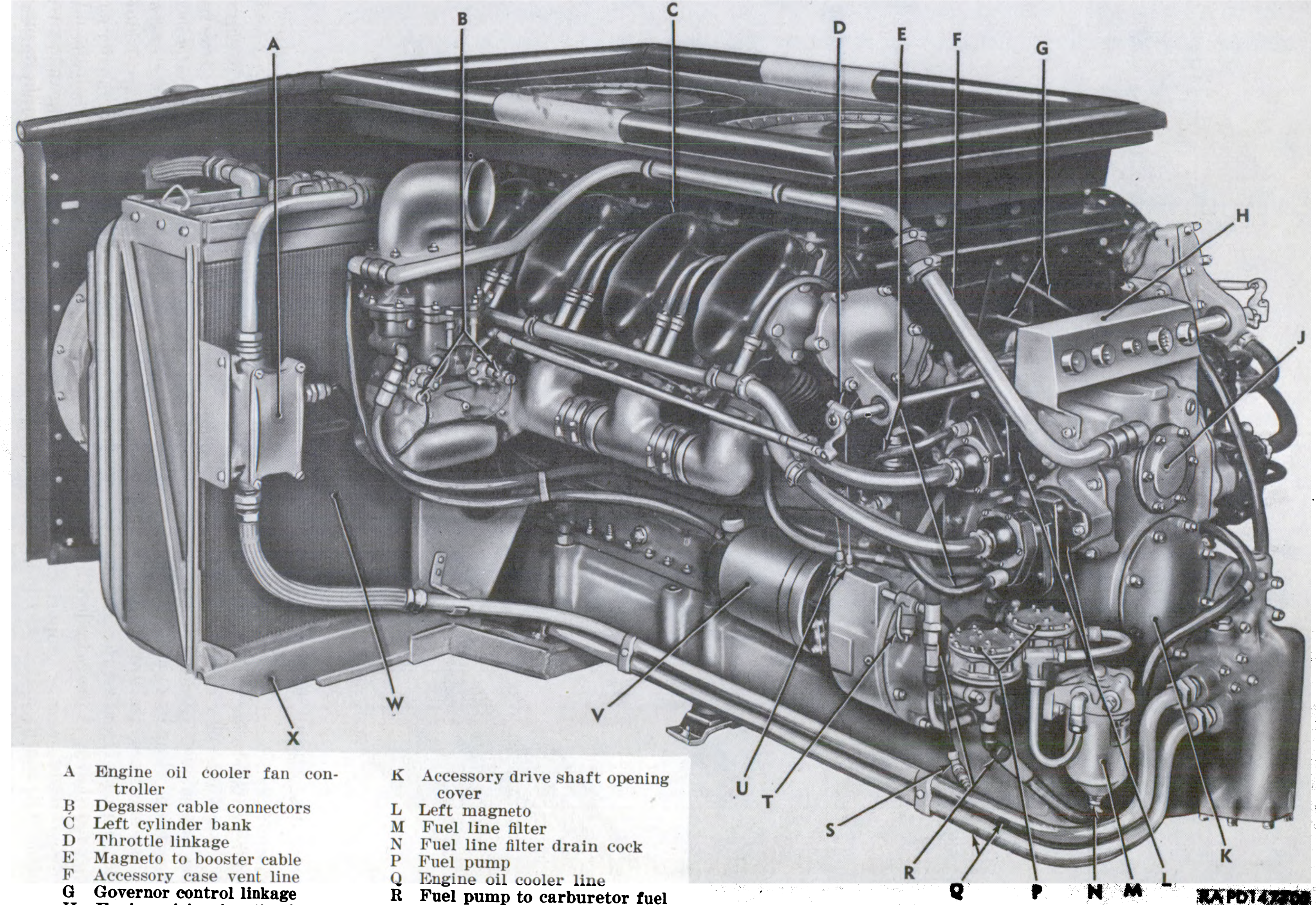


Figure 138. Air-cooled, 6-cylinder, opposed-cylinder engine with transmission being removed from tank.

from the crankshaft, causing them to rotate at high speed. The fans circulate air through the openings around the cylinders so that cooling takes place. Figure 138 shows the cooling system of an air-cooled 6-cylinder, opposed-cylinder engine. This engine has one fan instead of two as with the 12-cylinder engine. The effect is the same; the cooling air circulated around the cylinders by the fan helps to cool the engine.

b. Oil Coolers. Oil coolers play a part in keeping the engine from overheating. Figure 139 shows the oil cooler used on the V–12 air-cooled engine. The heated oil from the engine passes through this cooler, which acts much like the radiator used with liquid-cooled engines. That is, it removes heat from the hot oil and returns relatively cool oil to the engine. Here, the oil picks up heat again and once more is cooled by the radiator. This action continues, with the oil playing an important part in removing excessive heat from the engine and thereby helping to prevent engine overheating. (See also par. 106*b*.)



A	Engine oil cooler fan controller
B	Degasser cable connectors
C	Left cylinder bank
D	Throttle linkage
E	Magneto to booster cable
F	Accessory case vent line
G	**Governor control linkage**
H	**Engine wiring junction box**
J	**Accessory-driven shaft front support bearing cover**
K	Accessory drive shaft opening cover
L	Left magneto
M	Fuel line filter
N	Fuel line filter drain cock
P	Fuel pump
Q	Engine oil cooler line
R	**Fuel pump to carburetor fuel line**
S	**Primer fuel line**
T	**Primer line filter**
U	**Primer fuel line to cylinder**
V	**Starter**
W	**Right oil cooler**
X	**Oil cooler cradle**

Figure 139. V–12 air-cooled engine with oil cooler in place.

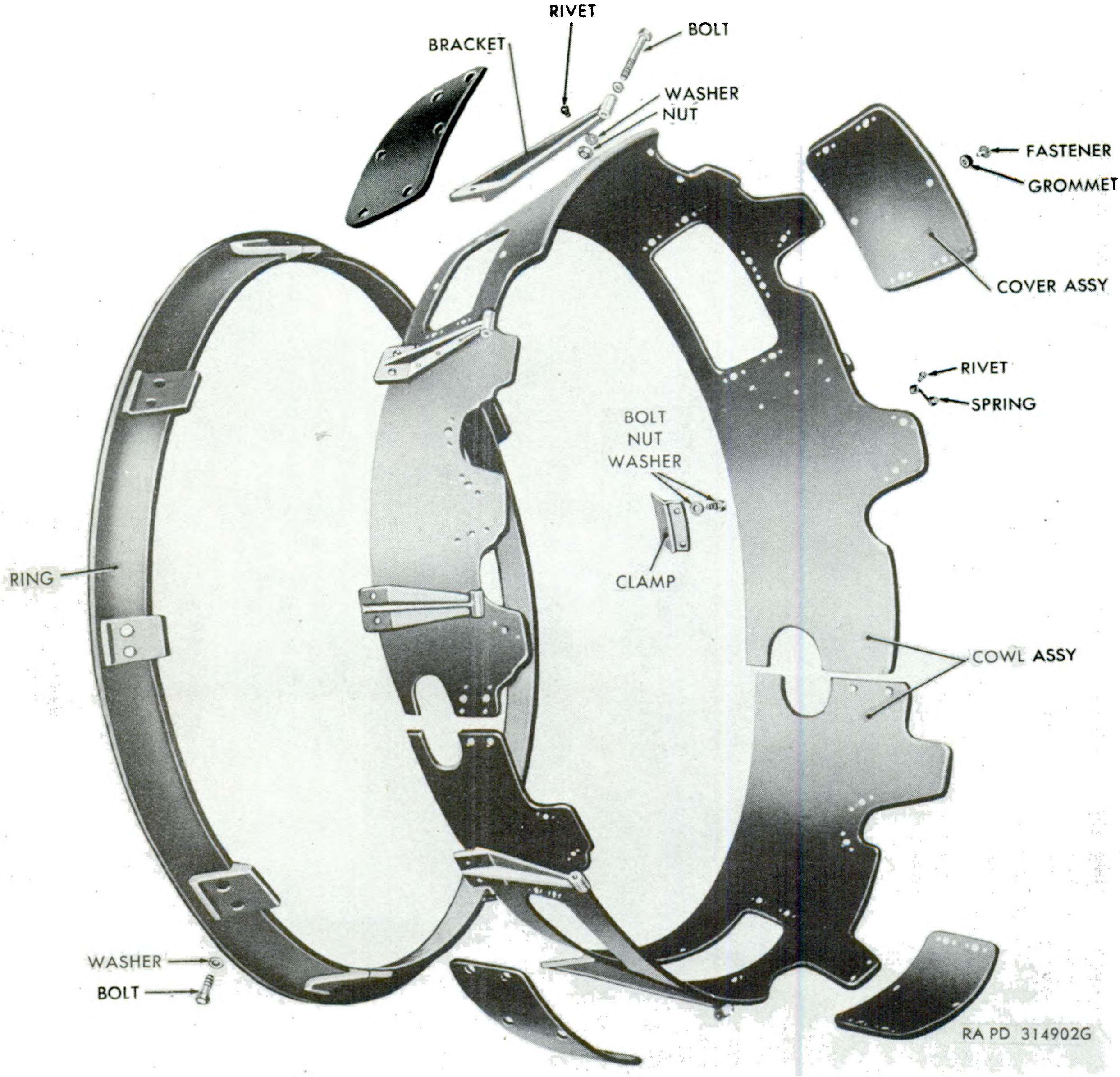

RIVET
BRACKET
BOLT
WASHER
NUT
FASTENER
GROMMET
COVER ASSY
RIVET
SPRING
BOLT
NUT
WASHER
CLAMP
RING
COWL ASSY
WASHER
BOLT
RA PD 314902G

Figure 140. Radial engine, cowling, or shroud.

98. Components, Radial Engine

a. Cowling. The engine cowling (fig. 140) surrounds the cylinders and helps keep the flow of air near them. It is made in three sections: the upper and lower sections and the outer ring. At the rear edge, the cowling is connected to the cowl mounting bosses, to the head and intercylinder baffles, and also at the front of the rocker boxes. At the front edge, the cowling is bolted to the outer ring, which provides a means of support and completes the cowling framework.

b. Cooling Fan. The cooling fan is mounted on the flywheel and operates within the front of the cowling as shown in figure 141. Its main job is to force air through the cooling passages formed between the cowling and baffles. In early engine design where there was little obstruction to the free flow of air, the objective of the cooling system was to force a large volume of air across the engine, with a relatively small change in pressure. However, the velocities over the rear heat-transfer surfaces of the cylinders were too low for good heat transfer, and some method had to be devised to increase the velocity of air and thereby increase the effectiveness of the fan.

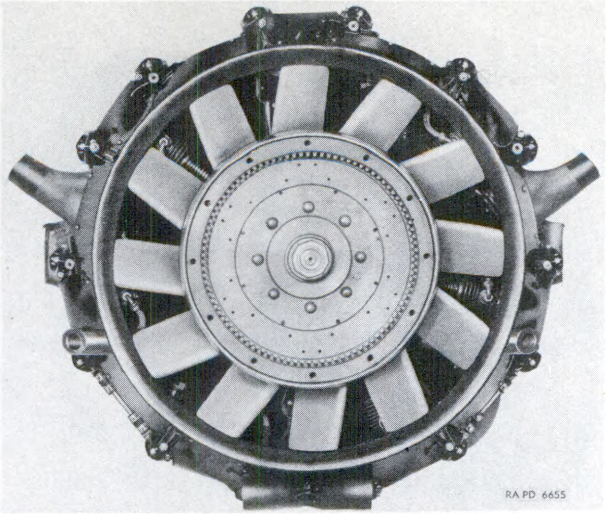


Figure 141. Radial engine cooling fan.

c. Baffles. Baffles, or deflectors (fig. 142), are used to obtain more effective use of the cooling air and to increase velocity of the air flow over the fins. They control the volume of air and confine it to useful heat-transfer passages. The result is an appreciable difference in pressure across the fin-baffle passages, which gives the desired increase in velocity for hastening heat transfer. (This is actually a simple application of the Venturi principle, namely, a restriction is used to increase velocity and decrease pressure.) The conventional arrangement of baffles places them on the rear of the cylinders only, where they direct air from the cooling fan to the fins on the rear sides of the cylinders. The unbaffled front portion is cooled by turbulence caused partly by air passing the front edge of the cowling and partly by rotation of the cooling fan.

d. Fins. The design of the fins has some effect on the velocity of air flow. Use of high fins exposes more surface for heat transfer but increases the size of the air passages, thus reducing the velocity of air flow. On the other hand, if low fins are used, the size of the air passages is reduced and velocity increases, but there is less surface available for heat transfer.

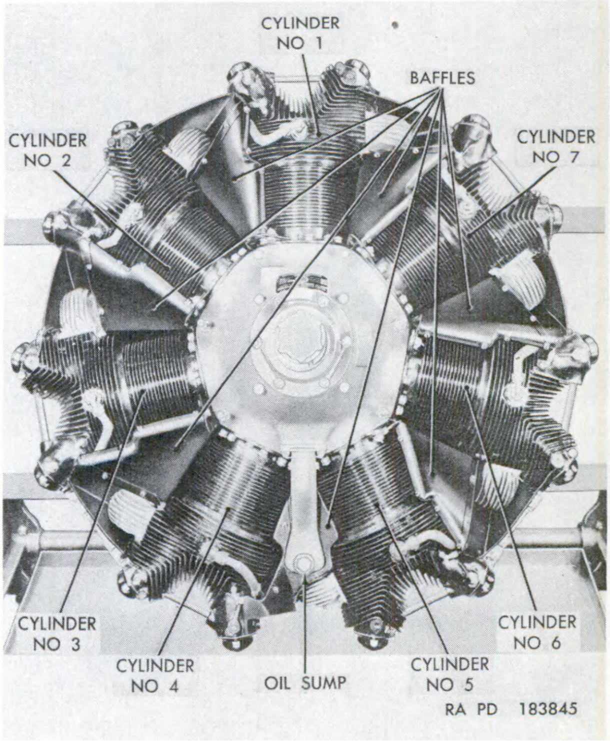


Figure 142. Radial engine baffles or deflectors.

CHAPTER 8

LUBRICATING SYSTEMS

99. Purpose

a. Engine lubricating oils have four functions: to prevent metal-to-metal contact in moving parts of mechanisms; to assist in carrying heat away from the engine; to clean the engine parts as they lubricate; and to form a seal between the piston rings and cylinder walls to prevent blow-by of the combustion gases.

b. The primary function of engine lubrication is to reduce the friction between moving parts. Oils are used to reduce friction not only because friction uses up power that otherwise would be available to drive the vehicle, but also because friction is destructive and creates heat that can cause moving parts to disintegrate. The greater the friction present between moving parts, the greater the energy required to overcome that friction. This increase in energy merely adds to the heat generated. Moving parts that have become deprived of oil will melt, fuse, or seize after a very short period of engine operation. It is lubrication alone which makes possible the use of plain bearings or bushings in a modern engine. Cylinders and pistons must be effectively lubricated to prevent burning or seizure of the parts as they move against one another; friction is severe at certain points, particularly along the surfaces of the piston rings where they contact the cylinder walls. Although the crankshaft, connecting-rod and piston-pin bearings, pistons, and rings are the most important engine lubrication points, there are many other parts which must have an adequate supply of oil. Valve stems must operate under stress and great ranges of temperature for long periods of time. Valve tappets and cams must be lubricated. All gears and accessory drives must be constantly bathed in oil, as must every other moving part in the engine that is subject to friction.

c. The oil is heated through contact with pistons and cylinder walls, after which it drops into the oil pan. The flow of air past the oil pan then cools the oil. In some instances where the oil pan is not exposed to a flow of air, it is necessary to add an oil-cooling unit (par. 106) which is a functional part of the water-cooling system.

100. Engine Oils

a. Mineral oil is used in most internal combustion engines. Racing and other engines which operate under exceptional conditions use castor oil or other special oils. Lubricating oils are designated according to certain characteristics they possess and according to their reactions to certain tests. Oil ordinarily is classified according to its viscosity.

b. The viscosity of an oil refers to its resistance to flow. When oil is hot, it will flow more rapidly than when it is cold. In cold weather, therefore, oil should be thin (low viscosity) to permit easy flow. In hot weather, oil should be heavy (high viscosity) to retard the rate of flow. The atmospheric temperature in which a vehicle is to operate determines whether an engine oil of high or low viscosity should be used. If, for example, too thin an oil were used in hot weather, the oil would literally burn up; consumption would be excessively high; and the lubricating cushion between moving parts would be too thin to provide adequate protection for the parts. In cold weather, heavy oil would not give adequate lubrication because its flow would be sluggish; some parts of the engine might not receive oil at all.

c. Oils are graded according to their viscosity by a series of SAE (Society of Automotive Engineers) numbers. The Army has standardized its engine oils on three grades: SAE 10, SAE 30, and SAE 50. The higher the SAE number, the more viscous, or heavy, the oil. This method of designating oils has no connection with the quality of the oil.

d. Oil does not wear out, but it does become contaminated and diluted. When dust enters through the carburetor, some of it mixes with other foreign material to form deposits in the combustion chamber. Some of the dust also moves down beyond the piston rings and into the crankcase. This dirt, together with dirt entering through the crankcase breather pipe, mixes with oil and is deposited on the bearings, causing excessive wear. Water, one of the products of combustion, will seep by the piston rings as steam (especially in cold weather) and will condense in the crankcase. This water emulsifies with the oil and with any dirt or foreign matter present to form a thick sludge which clogs up the oil lines and lubricating passages. Contamination of engine oils is minimized by controlling engine temperature, by an air cleaner on the carburetor, by oil filters, and by controlled crankcase ventilation.

e. When lubricating oil becomes diluted with gasoline, its viscosity decreases, and some of its lubricating qualities. Excessive use of the choke causes an overrich mixture to be forced into the cylinders. The excess gasoline remains in a liquid state and drains by the piston rings into the crankcase, where it mixes with the oil. When the engine operates at higher temperatures, this condition is corrected as the excess gasoline vaporizes in the crankcase and is carried off through the ventilation system. Presence of gasoline will not lower the oil level, but will maintain or even raise it; however, the lubricating quality of the oil is definitely reduced.

101. Oil Pumps

a. Oil pumps are mounted either inside or outside the crankcase, depending on the design of the engine. They usually are mounted so that they can be driven by a worm or spiral gear directly from the camshaft. Oil pumps are of four general types: gear, rotor, vane, and plunger. The gear and rotor oil pumps are the types most commonly used in automotive engine lubrication systems. They are described in *b* and *c* below. Vane and plunger-type pumps are described in paragraph 80.

b. Gear oil pumps are shown in figures 143 and 144. In this type, a gear driven by the camshaft drives a companion gear. Oil is forced into the pump cavity, around each gear, and out the other side into the oil passages. The pressure is derived from the action of the meshed gear teeth, which prevents oil from passing between the gears and, instead, forces it around the outside of each gear. The two radial-engine pumps, the main pump and the front scavenger pump, are both of the gear type. The main pump is divided into two separate sections: a pressure pump and a scavenger pump. The pumps have two spur gears with large teeth for each section. The pressure section supplies oil for lubrication of the internal circuit; the scavenger section returns oil from the rear of the sump to the supply tank. The pump is driven through a bevel gear, which is driven by a similar gear on the left magneto drive shaft. The oil pump incorporates a pressure relief valve, which is a spring-loaded ball that rises when the desired pressure is reached and allows the excess oil to be delivered to the inlet side of the pump. Pressure regulation is accomplished by turning the adjusting screw, which increases or decreases the tension in the spring. The front scavenger pump is also a gear-type pump. It is built into the crankcase front section and is driven directly off the crankshaft. Oil from the front part of the sump is forced through an external tube to the front scavenger pump, where it is returned to the supply tank. The scavenger section of the main pump picks up oil from the main part of the sump.

c. The rotor oil pump (fig. 145) makes use of an inner rotor with lobes that match similarly shaped depressions in the outer rotor. Figure 146 shows the manner in which the two rotors fit together. The inner rotor is off-center from the outer rotor. The inner rotor is driven and, as it rotates, it carries the outer rotor around with it. The outer rotor floats freely in the pump body. As the two rotors turn, the openings between them are

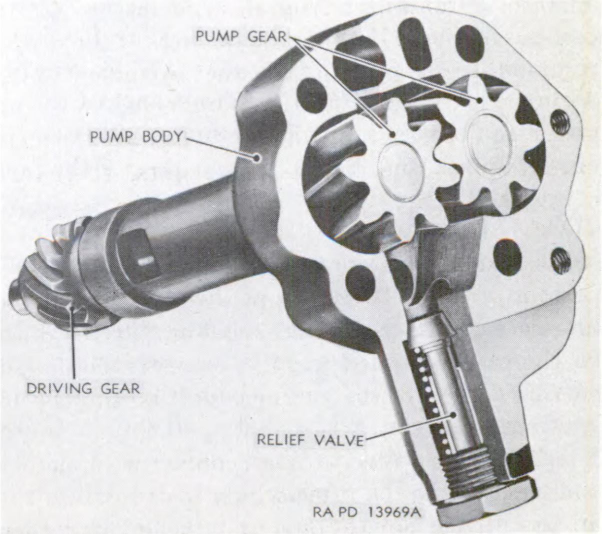


Figure 143. Gear-type oil pump.

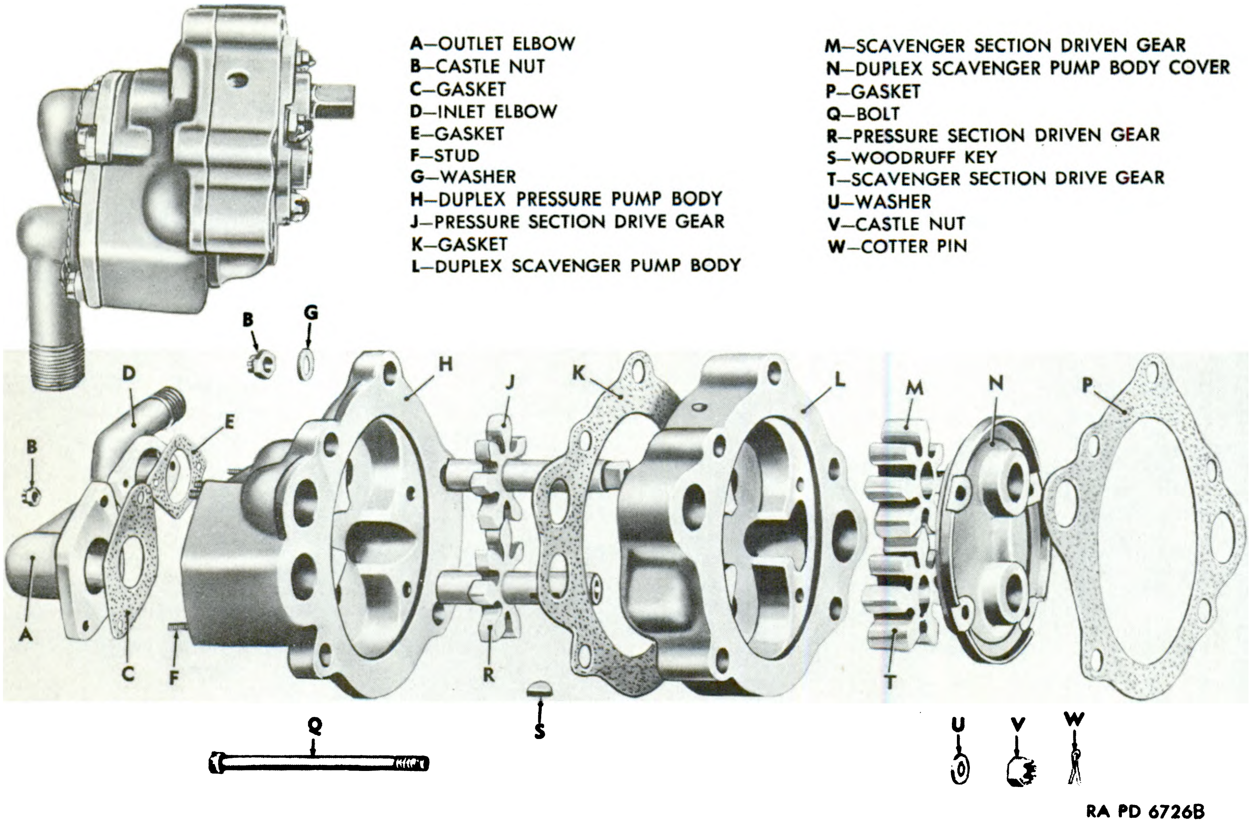

A—OUTLET ELBOW
B—CASTLE NUT
C—GASKET
D—INLET ELBOW
E—GASKET
F—STUD
G—WASHER
H—DUPLEX PRESSURE PUMP BODY
J—PRESSURE SECTION DRIVE GEAR
K—GASKET
L—DUPLEX SCAVENGER PUMP BODY
M—SCAVENGER SECTION DRIVEN GEAR
N—DUPLEX SCAVENGER PUMP BODY COVER
P—GASKET
Q—BOLT
R—PRESSURE SECTION DRIVEN GEAR
S—WOODRUFF KEY
T—SCAVENGER SECTION DRIVE GEAR
U—WASHER
V—CASTLE NUT
W—COTTER PIN
B
G
D
H
J
K
L
M
N
P
B
E
A
C
F
R
T
Q
S
U
V
W
RA PD 6726B

Figure 144. Radial engine combination pressure and scavenger gear-type oil pump.

filled with oil. This oil is then forced out from between the rotors as the inner-rotor lobes enter the openings in the outer lobes. This action is much like that in the gear-type pump. As the oil is forced out, it is forced through the oil lines to the various engine parts requiring lubrication. The rotor oil pump (fig. 145) is actually two pumps in one. The pressure section furnishes oil under pressure to the engine. The scavenging section picks up oil from the front part of the oil pan and delivers it to the oil sump. This keeps the oil circulating from the front part of the pan.

102. Oil Gages

Normally there are two oil gages in an engine: one indicates the pressure of the oil in the lubricating system, the other indicates the oil level in the oil pan if the gage is in a wet-sump system. In the case of radial engines, oil is measured by oil-level gages located in oil storage tanks.

a. Pressure Gage. The pressure gage is mounted on the instrument panel. It is calibrated in pounds per square inch or in some other comparative system to indicate the pressure in the lubrication system. There are two types of oil pressure gage, mechanical and electrical. In the mechanical type, the gage on the instrument panel is connected to an oil line tapped into the main oil supply passage leading from the pump. The pressure of the oil in the system acts on a diaphragm within the gage, causing a needle to register on a dial. In the electrical type, the oil pressure operates a signaling device on the engine which signals electrically to a dash gage. The dash gage then indicates the oil pressure. Paragraph 173 contains data on electrically operated gages. Vehicles are fitted with proper gages, and instructions as to the pressure which should be maintained may be found in pertinent technical manuals. If some part of the engine lubricating system becomes clogged, the pressure indicated on the gage will rise abnormally. New or cold oil also will produce high pressure readings.

b. Oil-Level Gage. The oil-level gage is usually of the bayonet type. It consists of a small rod which extends into the oil pan through a small hole in the side of the crankcase near the oil filler opening. It is marked to show "*EMPTY*", "*LOW*", and "*FULL*" *oil levels*. Readings are taken by pulling the gage out from its normal place in the crankcase, wiping clean, replacing and again removing and noting the height of the oil on the lower or marked end.

c. Warning Lights. Electrically operated warning lights for indicating oil pressure are being used in combat vehicles. These lights register only abnormal pressures: too low or too high.

103. Oil Strainers

a. Most manufacturers of an in-line and V-type engines place at least one oil strainer or screen in the lubrication system (figs. 148 and 149). This is usually a fine-mesh bronze screen located so that all oil entering the pump from the oil pan must flow through it. The strainer will usually be hinged to the oil pump inlet so that it floats on top of the oil. Thus, all oil taken into the pump comes from the surface. This prevents the pump from drawing oil from the bottom of the oil pan where dirt, water, and sludge are likely to collect.

b. The radial engine lubrication system has two finger-type screen strainers, one course and one fine. The coarse strainer (fig. 149) is in the rear of the sump, and oil is forced through it on the way to the scavenger section of the main oil pump. The fine strainer is located in the oil pump to the right of the governor. Oil passes through this strainer on its way from the supply tank to the pressure section of the main pump. Most strainers are designed so that they will be collapsed by high oil pressure if they become clogged, thereby preventing the possibility of a complete stoppage of oil flow and consequent damage to the engine.

104. Oil Cleaner (Filter)

a. The oil cleaner or filter is placed in the oil line above the pump (fig. 148). It filters the oil and removes most of the impurities that have been picked up by the oil as it has circulated through the engine and have not been caught by the strainer. The cleaner is mounted outside the engine and is connected so that part or all of the oil passes through it each time the oil is circulated through the engine. Some filters, called *full-flow filters*, are designed to handle the full output of the oil circulating pump, and all of the oil passes through them before being distributed to the engine parts. Other types divert only a small quantity of the oil each time it is circulated and, after filtering it, return it directly to the oil pan.

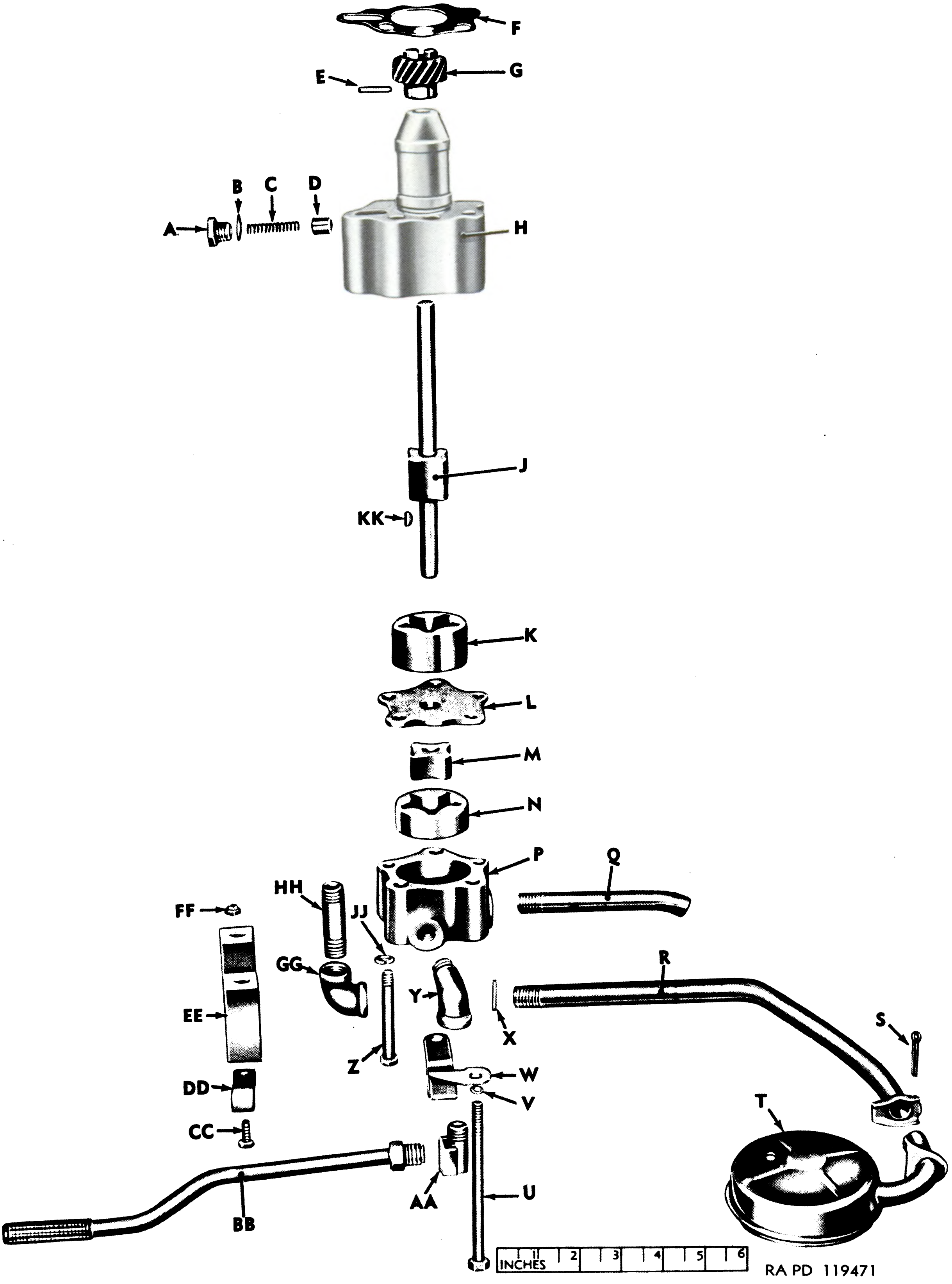
b. A typical oil filter is shown in figure 150. The filtering element consists of an arrangement of screens and a filtering material capable of retaining impurities as the oil is forced through. Filters eventually become blocked with impurities so that oil cannot pass. For this reason, most filters are provided with relief or bypass valves which allow the oil to flow around the filter when the back pressure caused by clogging is greater than the tension of the relief-valve spring. Some filters must be replaced after they are clogged; in others, the filter element can be removed and cleaned.

c. The radial and V-type engine oil filter is usually the disk type (fig. 151). It consists of a cartridge containing a series of stationary disks or cleaning blades and a second set of movable filtering disks attached to a shaft. The oil passing into the engine flows from the outside of the filtering disks to the inside through narrow slots between the disks, the dirt collecting on the outer surfaces. Cleaning is accomplished by turning the shaft; the movable disks pass between the stationary cleaning blades and the dirt drops down into the chamber below the filter, where it stays until the filter unit is removed for cleaning. The movable filtering disks are turned by hand or by a hydraulic unit on top of the filter. Oil returning from the engine to the supply tank is used to operate the hydraulic unit.

105. Crankcase Ventilators

Gasoline vapor and steam are harmful if they are allowed to remain in the crankcase oil. Steam will condense and mix with oil to form sludge; gasoline vapor will condense and dilute the oil. There are two methods of removing these vapors from the crankcase. The first, or nonpositive, method consists of a breather tube which depends on the flow of air past its open end to remove the vapors. The second, or positive, method utilizes engine intake manifold pressure to circulate air through the engine.

a. Breather Tube. One end of the breather tube opens into the crankcase above the oil level; the other end extends down under the vehicle, where there is sufficient air stream to create a low pressure at the open end of the tube (fig. 152). The pressure differential between the crankcase and the open end of the tube is sufficient to force


F
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R
Y
X
EE
S
Z
W
T
DD
V
CC
AA
U
BB
INCHES 1 2 3 4 5 6
RA PD 119471

Figure 145. Rotor-type oil pump—exploded view.

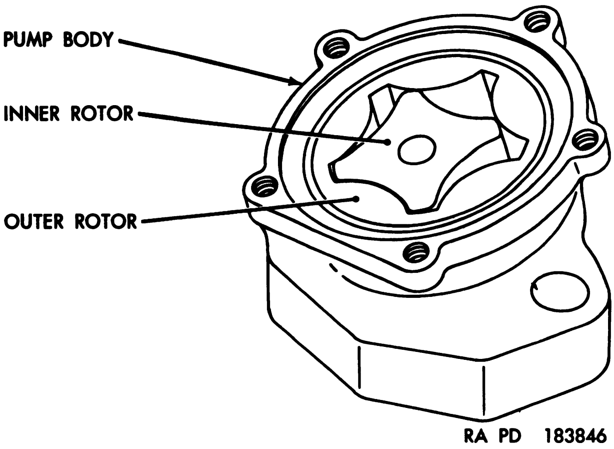


Figure 146. Inner and outer rotors of a rotor pump.

any vapors out of the crankcase. Some breather tubes are placed so that air from the cooling fan will flow through the tube and increase the pressure differential. There is an opening in the valve cover so that air can enter to replace that forced out the breather tube.

b. Positive Method. In the positive method, air is drawn through the engine by intake manifold vacuum; that is, the intake manifold vacuum draws air through the crankcase so that vapors are swept out of the crankcase. The air may follow either of two paths. In one, air is drawn directly into the crankcase through a filter or crankcase breather (fig. 153) similar to a carburetor air cleaner. After circulating through the crankcase and picking up vapors, the air is forced upward and out of the engine through an opening into the valve cover. It is then drawn through a tube connected to the intake manifold. This tube has a restriction to regulate the amount of vapor being drawn into the manifold, and thus minimizes the effect of the vapor on the fuel-air ratio of the mixture being delivered to the manifold by the carburetor. In the second path, air enters through a filter in the crankcase breather which is mounted on top of the valve cover (fig. 154). This breather also serves as a filler point for adding oil to the engine. In operation, air is taken through the shutoff valve (which is open when the ventilating system is operating), through the filter, and into the valve compartment. From there, it passes down into the crankcase and is withdrawn from the crankcase through a tube connected between the crankcase and the intake manifold. This second arrangement is in general use in waterproofed vehicles. The breather shutoff valve is operated by a control knob in the driver's compartment and is for use only when the vehicle is fording. Under this condition, to prevent water from entering the crankcase, the knob is pulled out to shut the valve. Immediately after the fording operation is completed, the knob must be pushed back in to re-establish crankcase ventilation. In connection with crankcase ventilators, it should be emphasized that, when possible, an engine should be operated at a coolant temperature of over 140° F. so that the volatile impurities in the crankcase will stay in a gaseous state and those already condensed will be vaporized and rise above the oil, where they can be removed.

c. Breather, Radial Engine. Most radial engines use a variation of the breather tube. Like in-line engine crankcases, the radial engine crankcase has pressures generated within it by expansion of gases, by leakage of pressure past the piston rings, and by other similar actions. It is necessary to have some form of breather opening to relieve the pressures. Formerly, the radial engines on automotive vehicles used a system of internal breathing between the accessory and main crankcase sections; the only external vent was located in the front section and was connected with the external tank where the oil supply

---

A	Valve cap
B	Valve cap gasket
C	Valve spring
D	Valve
E	Groove pin
F	Gasket
G	Drive gear
H	Body
J	Pressure rotor shaft assembly
K	Outer pressure rotor
L	Spacer
M	Inner scavenger rotor
N	Outer scavenger rotor
P	Scavenger body
Q	Scavenger outlet tube
R	Pump to float connection
S	Cotter pin
T	Float assembly
U	Screw
V	Lockwasher
W	Float line locating bracket
X	Dowel pin
Y	Street elbow
Z	Bolt
AA	Tube elbow
BB	Scavenger intake line assembly
CC	Bolt
DD	Closed clip
EE	Scavenger intake line support
FF	Safety nut
GG	Pipe elbow
HH	Pipe nipple
JJ	Lockwasher
KK	Woodruff key

Figure 145—Continued.

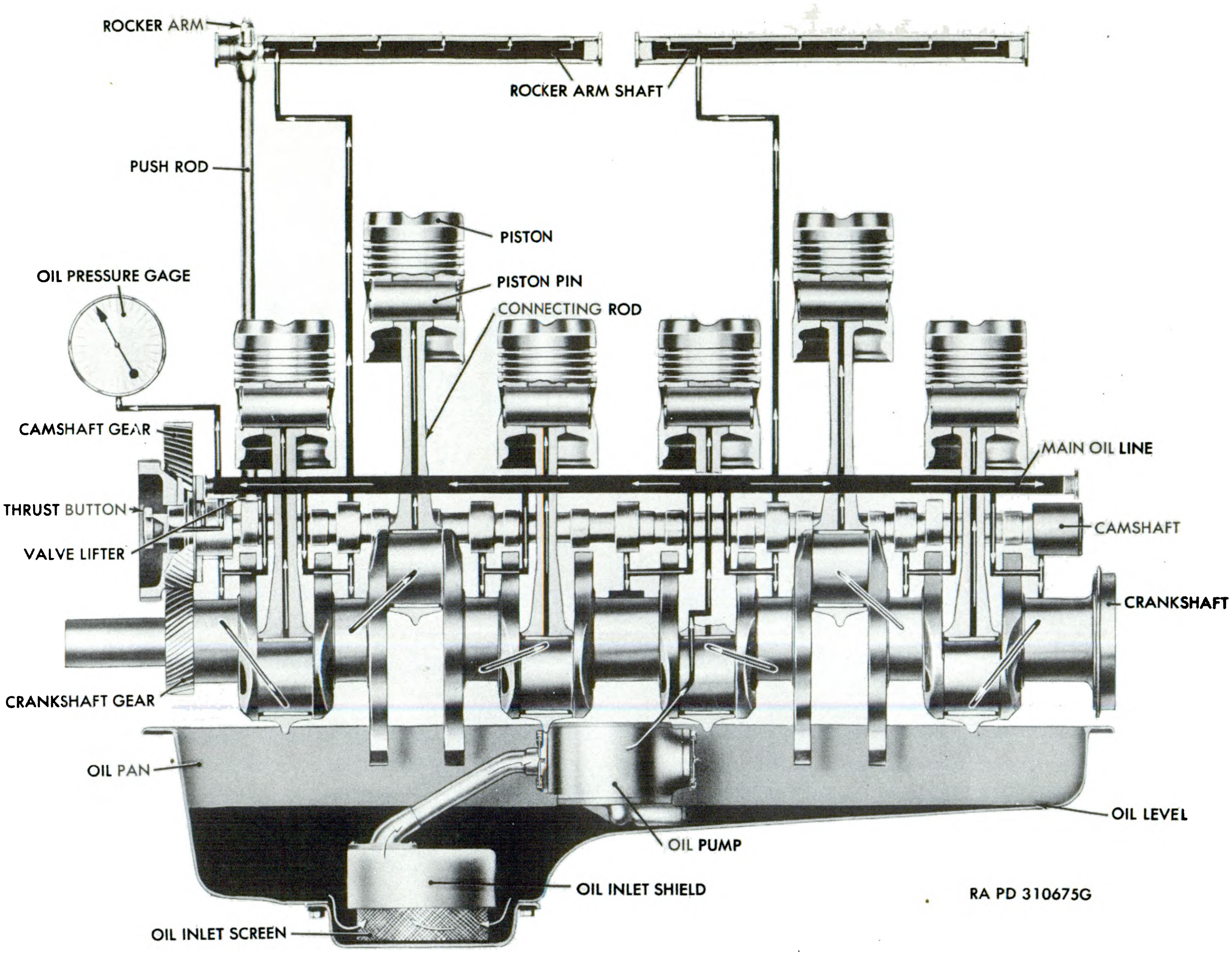

ROCKER ARM
ROCKER ARM SHAFT
PUSH ROD
PISTON
PISTON PIN
CONNECTING ROD
OIL PRESSURE GAGE
CAMSHAFT GEAR
MAIN OIL LINE
THRUST BUTTON
CAMSHAFT
VALVE LIFTER
CRANKSHAFT
CRANKSHAFT GEAR
OIL PAN
OIL LEVEL
OIL PUMP
OIL INLET SHIELD
RA PD 310675G
OIL INLET SCREEN

Figure 147. Lubrication system in in-line and V-type engines.

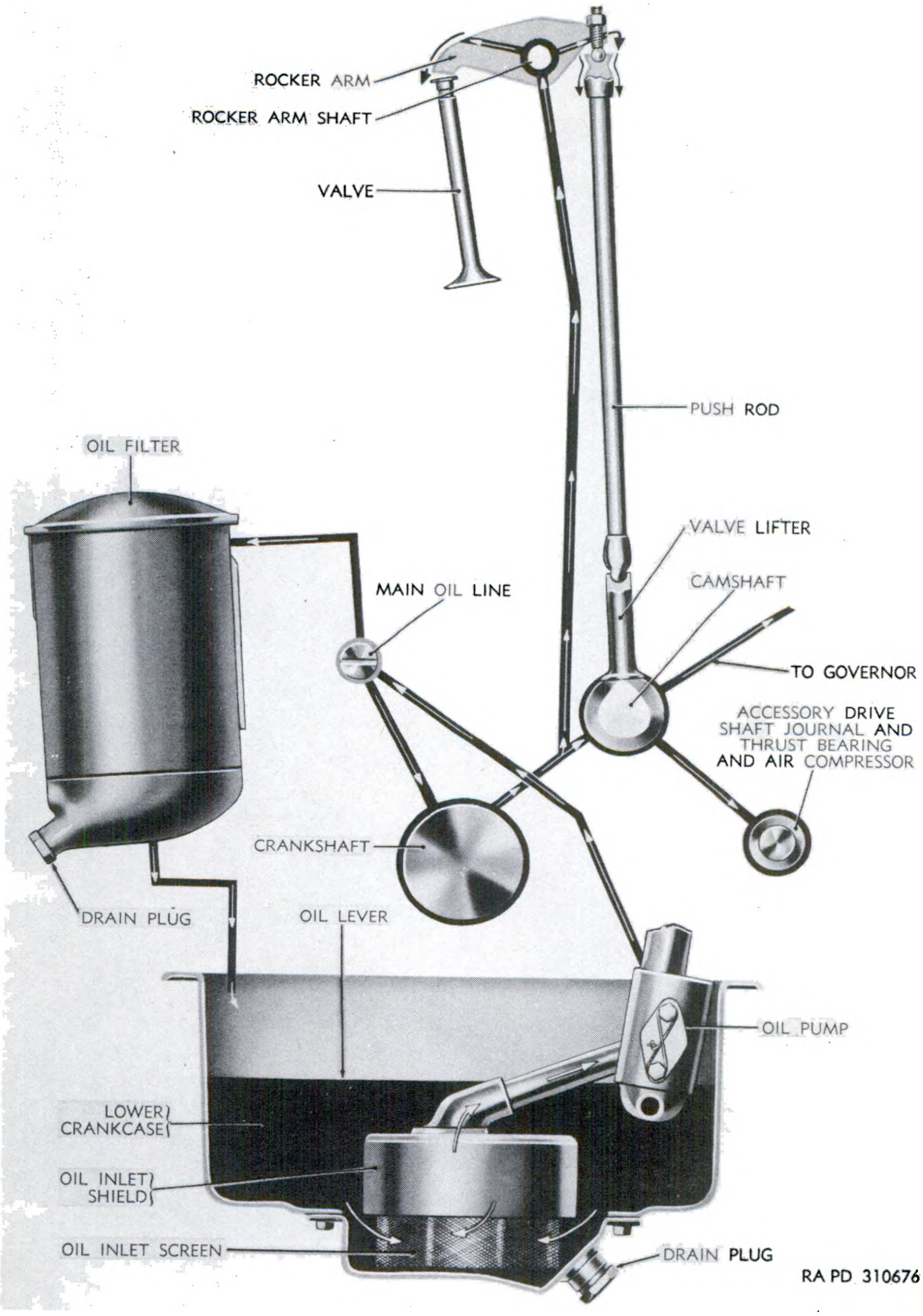

ROCKER ARM
ROCKER ARM SHAFT
VALVE
PUSH ROD
OIL FILTER
VALVE LIFTER
CAMSHAFT
MAIN OIL LINE
TO GOVERNOR
ACCESSORY DRIVE SHAFT JOURNAL AND THRUST BEARING AND AIR COMPRESSOR
CRANKSHAFT
DRAIN PLUG
OIL LEVER
OIL PUMP
LOWER CRANKCASE
OIL INLET SHIELD
OIL INLET SCREEN
DRAIN PLUG
RA PD 310676

Figure 148. Lubrication system of in-line and V-type engines.

is carried. This permitted oil vapor to condense and return to the system rather than be lost, as it would be if the engine were vented directly to the atmosphere. Normally, however, the engine has external vents leading from the accessory and tappet (rear part of main crankcase sec.) sections through an air filter to the atmosphere. Air goes through the filter in two directions. When the engine is cool and the pressure inside the crankcase is low, air is drawn in through the

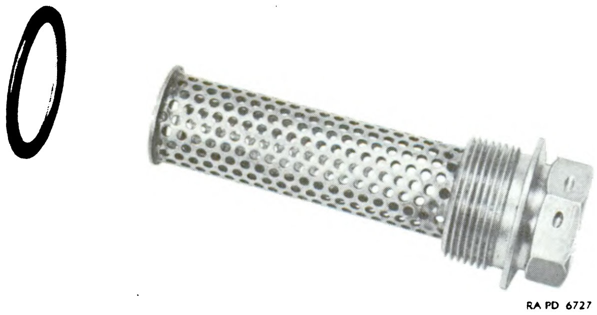


Figure 149. Oil strainer.

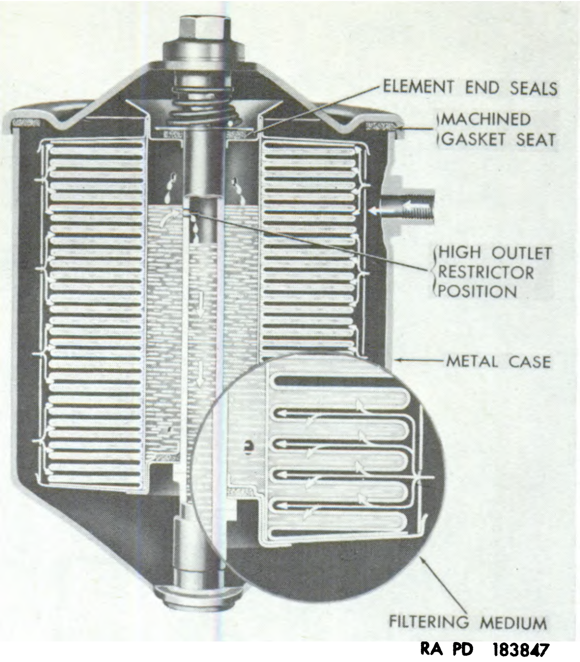

ELEMENT END SEALS
MACHINED GASKET SEAT
HIGH OUTLET RESTRICTOR POSITION
METAL CASE
FILTERING MEDIUM
RA PD 183847

Figure 150. Oil filter.

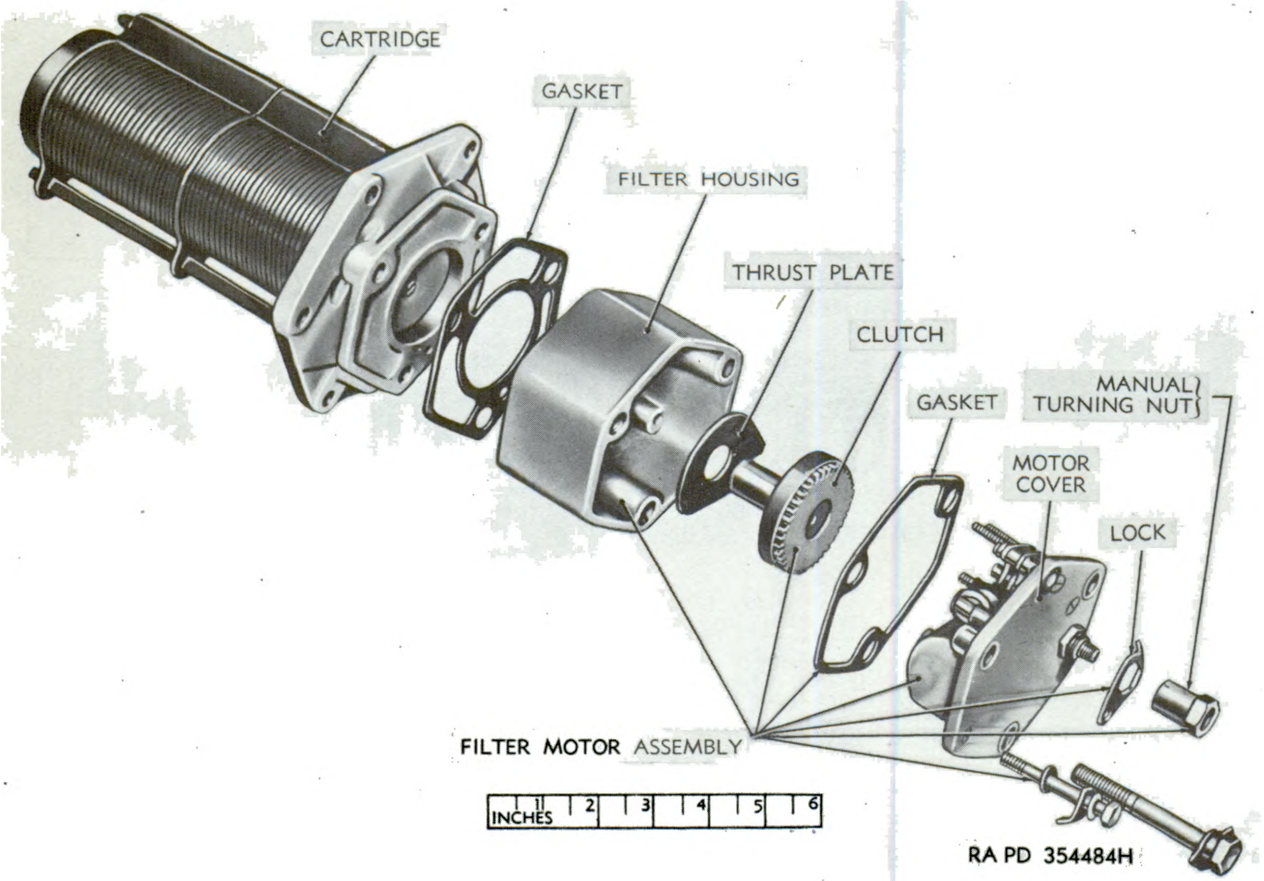

CARTRIDGE
GASKET
FILTER HOUSING
THRUST PLATE
CLUTCH
GASKET
MANUAL TURNING NUT
MOTOR COVER
LOCK
FILTER MOTOR ASSEMBLY
INCHES 1 2 3 4 5 6
RA PD 354484H

Figure 151. Disk-type oil filter disassembled.

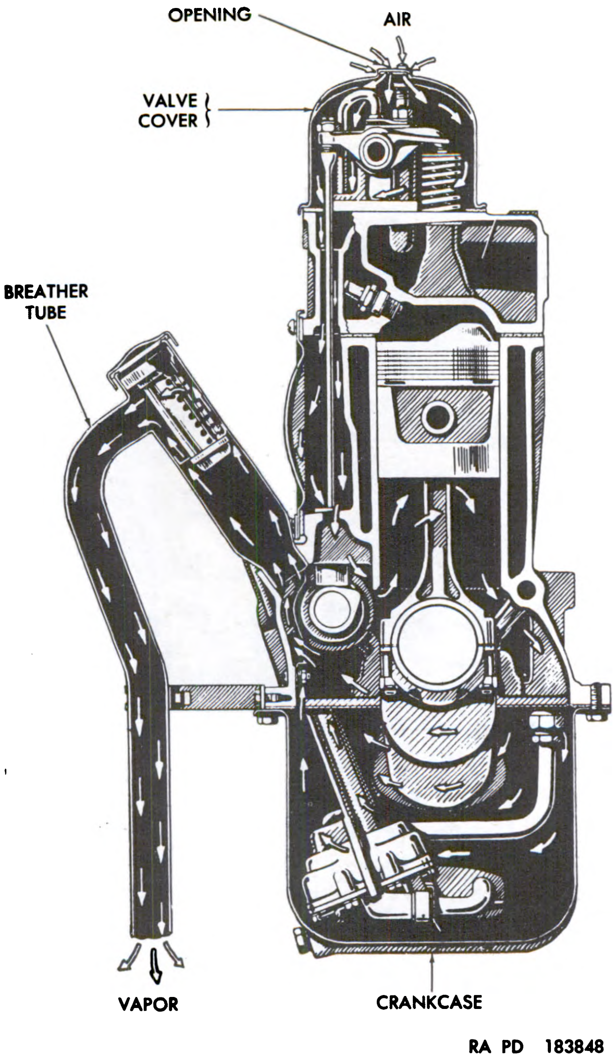


Figure 152. Crankcase breather tube.

filter. As the engine warms up and pressure develops, the pressure is relieved by the gases escaping through the filter.

106. Oil Temperature Regulator and Cooler

a. Oil Temperature Regulator. The oil temperature regulator is used to prevent the oil temperature from rising too high in hot weather and to assist in raising the temperature during cold starts in winter weather. The regulator (fig. 155) makes use of the liquid in the cooling system. It provides a more positive means of controlling oil temperature than does cooling by radiation of heat from the oil-pan walls. The regulator unit is made up of a core and a housing. The core through which the oil circulates is of cellular or bellows construction, and is built to expose as much of the oil as possible to the coolant which circulates through the housing. The regulator is attached to the engine so that the oil will flow through the regulator after passing through the pump. The oil leaves the regulator either cooled or heated, depending on the temperature of the liquid in the cooling system, and enters the oil passages to the engine parts.

b. Oil Cooler. The types of oil coolers used with combat vehicles consist of a radiator through which air is circulated by movement of the vehicle or by the cooling fan. Oil from the engine is passed through this radiator and back to the engine and to the oil supply tank. This radiator acts only to cool the oil and does not function as a regulator in which the temperatures may be increased during cold weather operations. Figure 139 shows a V–12 air-cooled engine with a radiator-type oil cooler. This engine uses two such oil coolers. The coolers cool both engine and transmission oils, having separate cores for each. The fans used with the oil coolers are driven from the driving gear in the transmission through a gear train and electrically operated clutches in the front fan shrouds. The clutches serve as a means

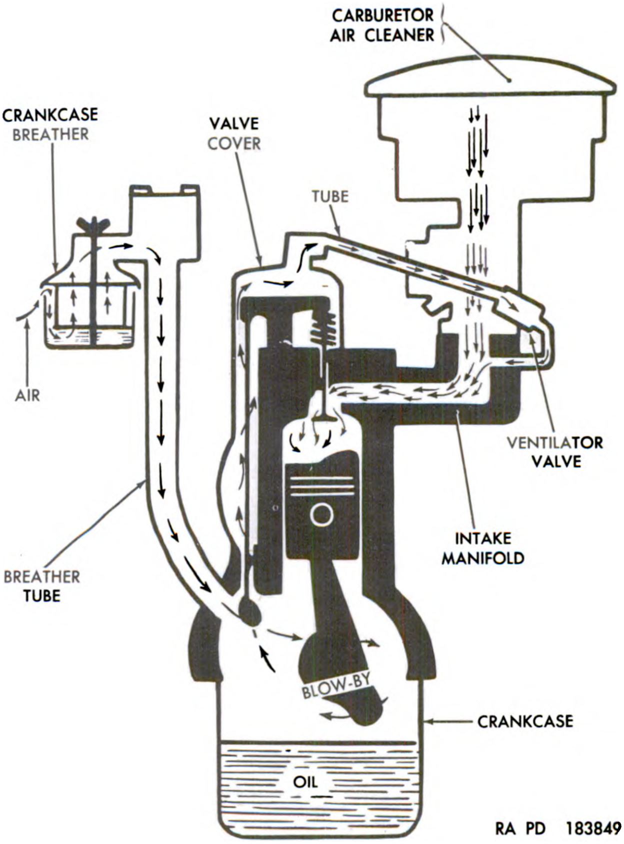


Figure 153. Positive crankcase ventilation.

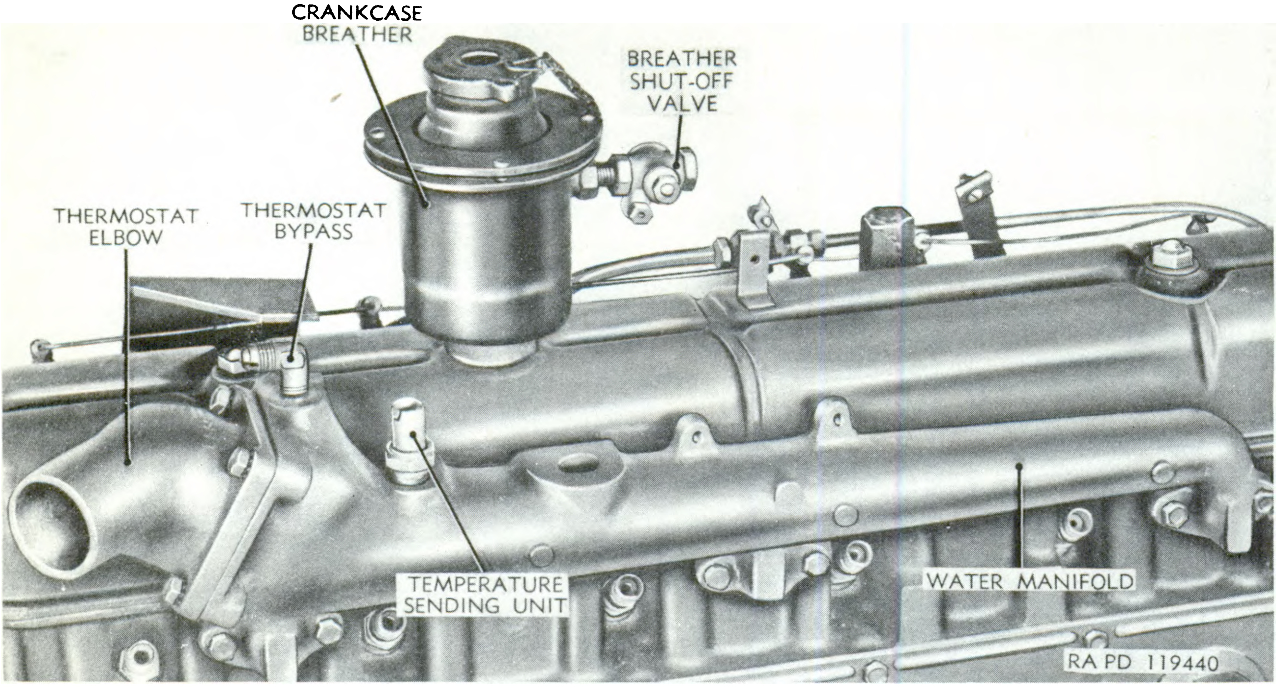


Figure 154. Crankcase breather and water manifold.

of regulating oil temperature since they engage only when the temperature exceeds a minimum value. When this minimum value is exceeded, thermoswitches close and cause the clutches to engage. The fans then operate. This permits faster engine warmup since the oil-cooler fans do not operate with the engine cold.

107. Types of Lubrication Systems

All important working parts of an engine are lubricated by oil carried in the crankcase. The fact that oil is always present in the crankcase explains why the lubricating system used in most in-line engines is known as a wet-sump system. The dry sump is common to radial engines. The oil in the in-line engine wet-sump system is circulated under pressure (force-feed) or splashed mechanically on the surfaces to be lubricated. The different methods of circulating the oil are known as splash, combination splash and force-feed, force-feed, and full force-feed.

a. Splash Lubrication System. The splash lubrication system is no longer used because its lubricating effect is too uncertain to meet the requirements of today's varied operating conditions. In the splash lubrication system, dippers on the connecting rods enter the oil in the crankcase with each crankshaft revolution, thus splashing the oil. The oil thereby thrown upward finds its way to the various moving parts in the engine to provide lubrication. As stated above, this system is too uncertain since a full crankcase means

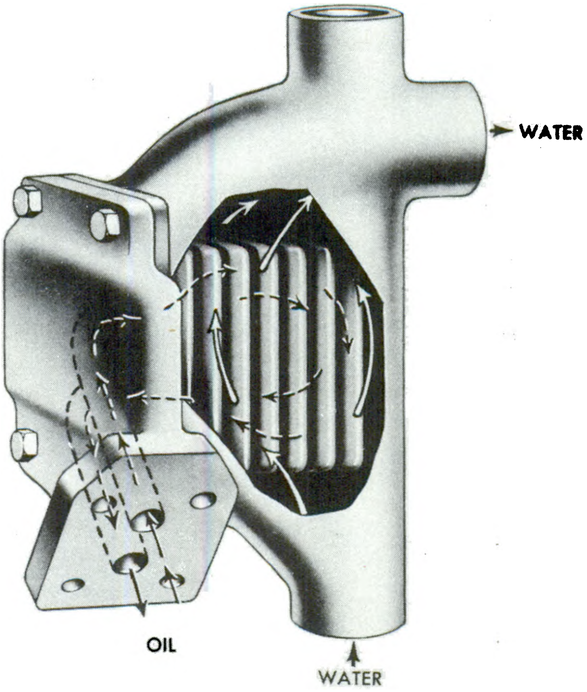
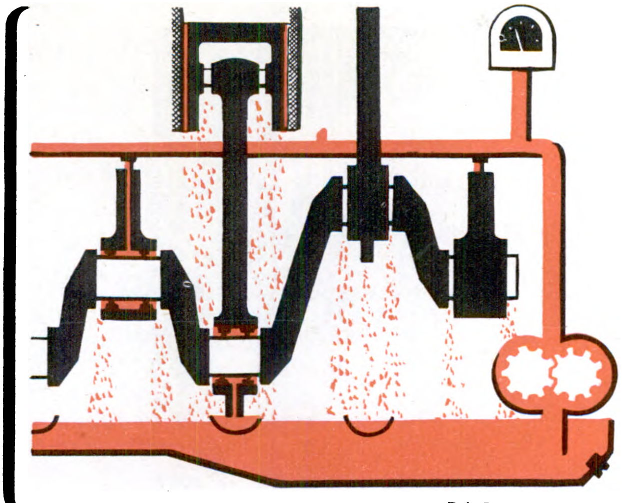


Figure 155. Oil temperature regulator (cooler).



RA PD 354375

Figure 156. Combination splash- and force-feed lubrication system.

heavy lubrication while a partly empty crankcase may result in inadequate lubrication and possible failure of the engine. In many engines today, however, a modified splash lubricating system is used which provides a uniform splashing effect even though there may be variations in the amount of oil in the crankcase. It does this by utilizing a pump that delivers oil from the crankcase to troughs under the dippers on the connecting rods, thus maintaining a constant level of oil into which the dippers can dip.

b. Combination Splash- and Force-Feed Lubrication System. In the combination lubrication system, oil is delivered to some moving parts by means of splash, and to other parts through oil passages from an oil pump in the crankcase. Figure 156 shows a system of this type. The oil pump at the lower right delivers oil under pressure directly to the main bearings through oil passages in the cylinder block. This oil keeps the main bearings supplied with a constant flow of oil. The oil circulates through the main bearings and drips back into the crankcase. Oil is also supplied under pressure to the camshaft bearings. In overhead valve engines, the valve mechanisms are lubricated by oil supplied by the oil pump, and it is pumped through passages in the cylinder block and by tubes to the hollow rocker-arm shaft. From there, the oil drains out to lubricate the valve mechanisms. The connecting rods, as well as the pistons, piston pins, and cylinder walls, are lubricated by splash from the effect of the dippers splashing into the oil troughs under them. The troughs are kept filled by the oil pump which delivers oil to them through oil nozzles. In some engines, the oil nozzles deliver an increasingly heavy stream with higher engine speeds (because of higher oil pump speed). At higher speeds, the oil stream is powerful enough to directly strike the oil dipper as it moves down toward the oil trough (fig. 157). This action causes a much heavier splash so that adequate lubrication of the piston and connecting rod bearings is provided at higher speeds.

c. Force-Feed Lubrication System. In the force-feed lubrication system (fig. 158), a somewhat more complete pressurization of lubrication is achieved. Oil is forced by the oil pump from the crankcase to the main bearings and camshaft bearings as in the system described in *b* above (and also to valve mechanisms in overhead valve engines). Also, oil is forced to the connecting rod bearings for positive lubrication of these bearings. In order to lead oil to the connecting rod bearings, oil passages (or *leads*) are drilled in the crankshaft. The oil enters these passages from openings in the main bearings and main journals. In some engines, these openings are simply holes that index once for every crankshaft revolution. This is sufficient to fill the oil passages in the crankshaft and feed oil to the connecting rod bearings. In other engines, there are annular grooves in the bearings through which oil can feed constantly into the hole in the crankshaft.

d. Full Force-Feed Lubrication System. In the full force-feed lubrication system (fig. 159), all the bearings mentioned in *c* above are lubricated by oil under pressure. This includes main bearings, camshaft bearings, connecting rod bearings, and valve mechanisms in overhead valve engines. In addition, the full force-feed lubrication system provides lubrication under pressure to the pistons and piston pins. This is accomplished by holes drilled the length of the connecting rod, from the connecting rod bearing to the piston pin bearing. Thus, oil under pressure enters the crankshaft oil passages from where it passes to the connecting rod bearing. From there, it enters the holes drilled in the connecting rod and passes up the rod passage to the piston pin bearing. This oil not only feeds out on the piston pin bearing to provide lubrication for it, but it also helps to lubricate the piston and cylinder wall.

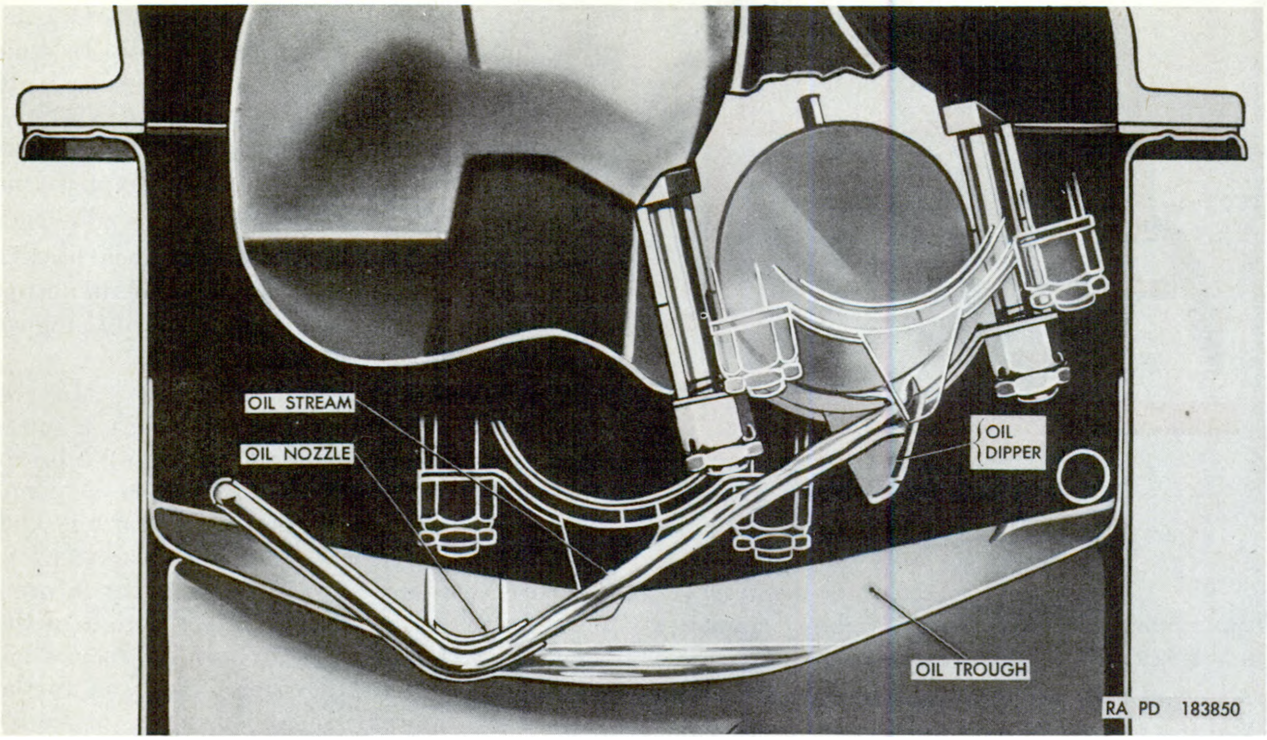

OIL STREAM
OIL NOZZLE
OIL DIPPER
OIL TROUGH
RA PD 183850

Figure 157. Dipper on connecting rod receiving oil stream from oil nozzle.

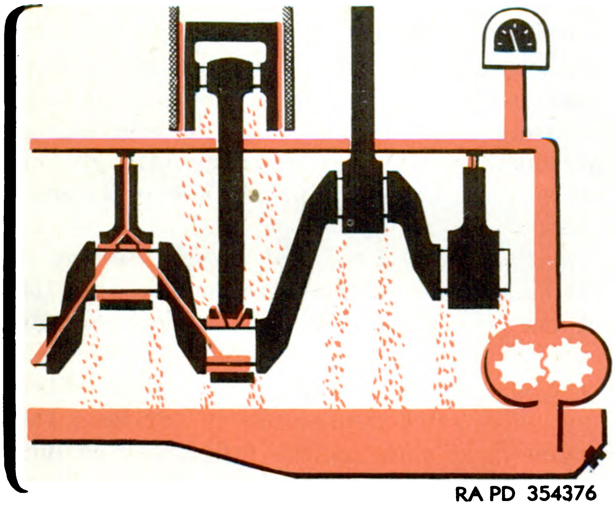

RA PD 354376

Figure 158. Force-feed lubrication system.

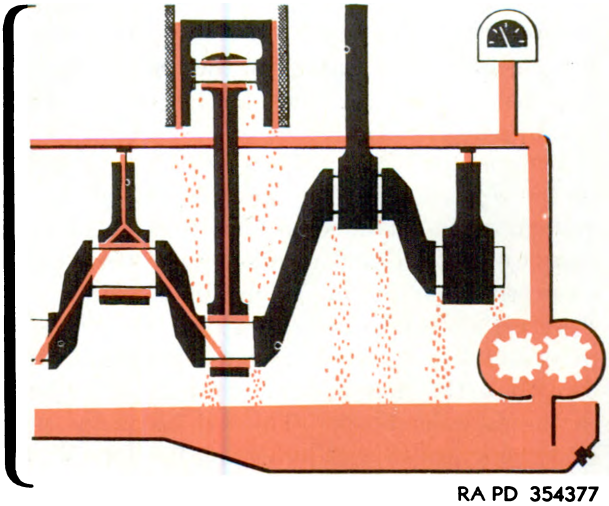

RA PD 354377

Figure 159. Full force-feed lubrication system.

CHAPTER 9

ENGINE ACCESSORIES UNDERWATER VENTILATING SYSTEMS

108. Purpose

a. Combat and transport vehicles, if expected to ford deep water or operate in surf landings, must be specially prepared or equipped to go through such an operation and be used immediately. This means that the vehicle must be able to go through fording or landing operations and continue to operate in a normal condition; that is, the special preparations must not reduce the operative effectiveness of the vehicle.

b. Late-type ordnance transport vehicles are specially designed and built for fording and landing operations without modifications. Necessary waterproofing and engine-accessory-ventilating systems are already installed on such vehicles. All "breathing" mechanisms on the vehicles are connected to the carburetor air cleaner and secure air through it. Most important, of course, is the engine, which requires large amounts of air for operation. But in addition, the carburetor float chamber, brake master cylinder, fuel tank, transmission and transfer, ignition distributor, and the crankcase ventilator are all vented through the air cleaner, (par. 109). For normal fording operations where a specified depth will not be exceeded (as, for instance, 30 inches on the ¼-ton 4x4 utility truck M38), no special preparations are required. For deep-water fording, special air intake and exhaust extension tubes must be installed. These raise the height of the intake and exhaust so that deeper water can be forded. All instruments, switches, starter, generator, regulator, battery vents, ignition filter, distributor, and ignition cables are waterproofed, since they will be immersed during fording operations.

c. With tanks and tanklike vehicles, the problems of waterproofing and engine ventilation are different from transport vehicles. With tanks, the hull itself must be made waterproof so the individual engine components do not require special treatment or venting. On this type vehicle, all normal or abnormal openings (cracks, seams, holes, etc.) must be tightly sealed so that no water can enter when the tank is immersed. Examples of normal openings that must be sealed include filled caps, machinegun mounts, hull ventilators, etc. These are generally sealed by use of nonhygroscopic tape and sealing compounds. Examples of abnormal openings that must be sealed include holes (missing bolts, etc.) and cracks or seams in the hull. These can be sealed by first caulking the larger holes with rags, and then covering all openings with sealing compound. In addition, special gun shield covers are used to prevent entrance of water around the shield. Special air intake and air exhaust stacks (fig. 160) must be installed, and sealing boots placed on machinegun ports in the hull. Details of all these preparations are covered in TM 9–2853.

109. Applications

(fig. 161)

a. Operation of a transport vehicle under water is made possible by the sealing, at time of manufacture, of all parts or assemblies which are affected immediately by the entrance of water. Watertight housings are provided for such parts as the instruments, switches, starter, generator, regulator, and distributor as well as other parts enumerated in paragraph 108. Further information on the waterproofing of electrical equipment can be found in subsequent paragraphs, as follows: generator (par. 129), regulator (par. 133), starter (par. 144), and ignition equipment (par. 150).

b. A series of ventilating tubes are required to provide venting of various accessories, as described in (1) through (6) below.

(1) The carburetor float chamber is vented to the air horn by an internal passage and is extended to the air cleaner tube by an external tube (F).

(2) The brake master cylinder is vented through tube (E) which extends up between the foot pedals to dash elbow (D),

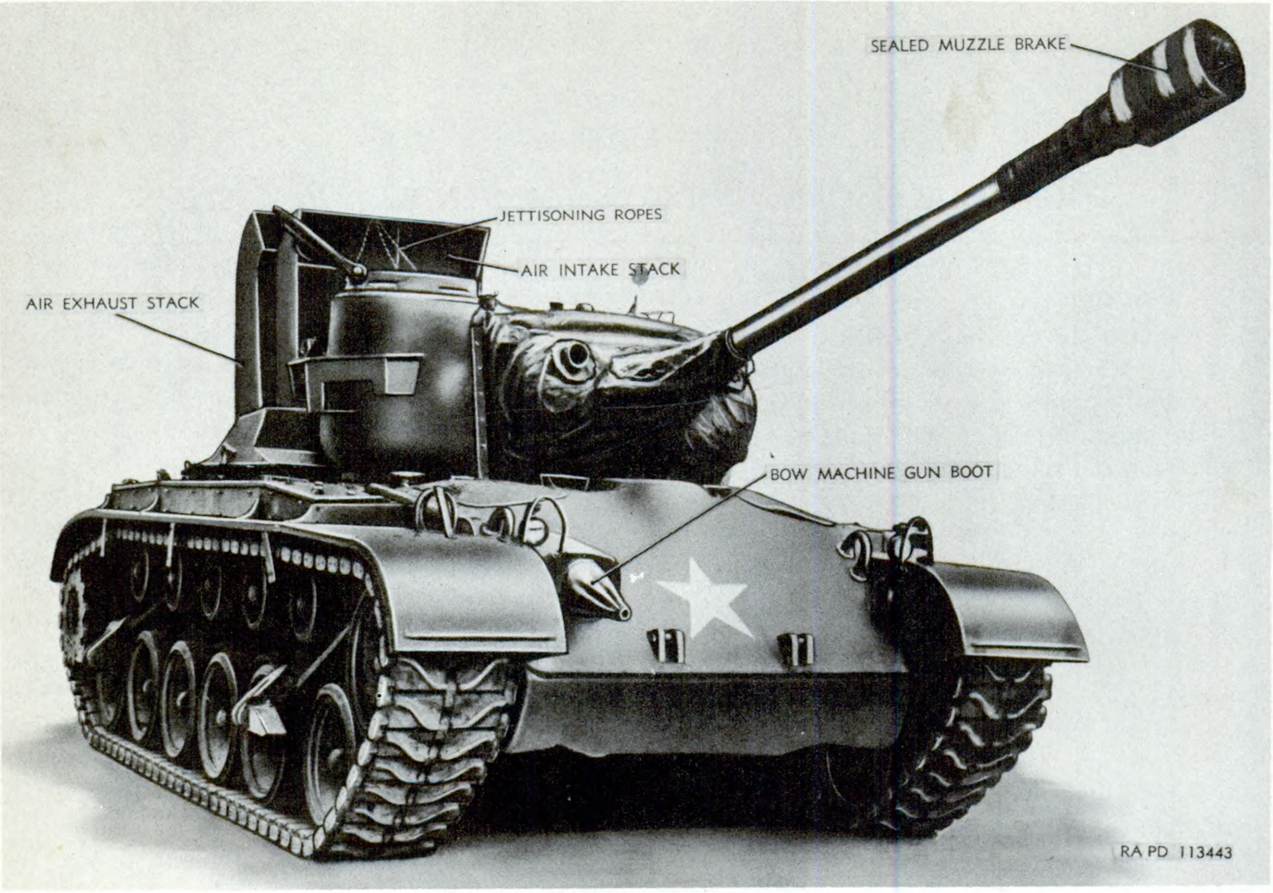


Figure 160. Tank prepared for deep-water fording.

mounted on the dash, and dash elbow to dash tee tube (C) to dash tee (Q) and air cleaner to dash tee tube (P) to air cleaner.

(3) The fuel tank is vented through gasoline tank to air cleaner vent tube (B) which connects to the air cleaner.

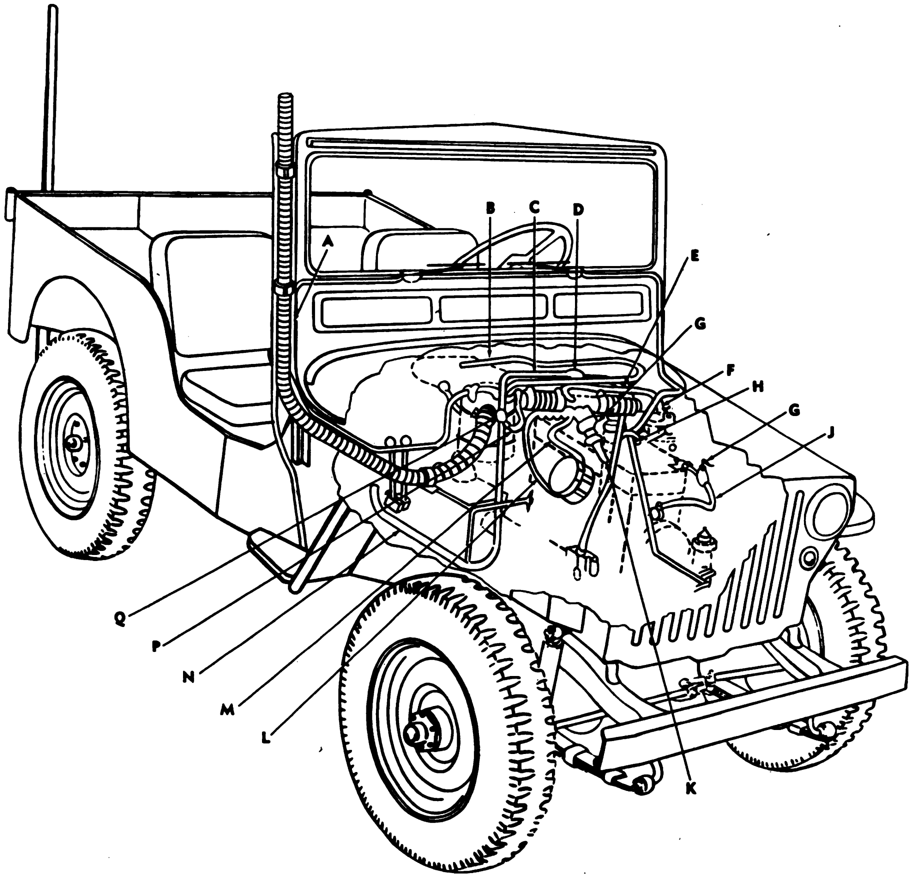
(4) The transmission and transfer are vented through transfer to dash tee vent tube (N) connected to the top of the transfer to the air cleaner through dash tee (Q) and air cleaner to dash tee tube (P).

(5) Positive circulation of air through the distributor housing is insured through connecting distributor to vacuum line tube (L) and distributor to air cleaner tube (M). One tube (L) from the air cleaner provides an air intake for the venting; the other tube (M) is connected to vacuum line tee (H) in the windshield wiper vacuum line. This vacuum connection provides positive ventilation and will draw off any water which might possibly enter or collect in the distributor. The elbow used as a connector at the end of the windshield wiper vacuum tube is connected to the tube leading to the distributor.

(6) The crankcase ventilation system must be shut off during engine immersion. This is accomplished by having a breather shutoff valve (fig. 154) in the breather linked to a shutoff knob in the driving compartment. When the valve is closed, a pressure builds up in the engine crankcase that prevents the entrance of water (par. 105*b*).

c. A special type air cleaner (fig. 162), mounted on the engine side of the dash panel, is used with underwater ventilating systems. The air cleaner functions in the same manner as other air cleaners, but it has a series of connecting tees by means of which the venting lines from the various accessories can be connected. As will be noted in figures 161 and 162, lines to the air cleaner are run from the fuel tank, distributor, brake master cylinder, etc. In addition, note that the air compressor (for the air brakes) also draws its air from the air cleaner. The flange to the left on the air cleaner shown in figure 162 provides a means of connecting the air intake extension.

d. It is extremely important, in any fording operation, to observe the procedures outlined in the applicable technical manual. These procedures specify the maximum depth of water to be forded by normal and by deep-water fording, the speed at which the vehicle should be driven (3 to 4 mph), the correct transmission gear ratio (low or low-low), etc.



A—WINDSHIELD WIPER TO AIR CLEANER VENT TUBE
B—GASOLINE TANK TO AIR CLEANER VENT TUBE
C—DASH ELBOW TO DASH TEE TUBE
D—DASH ELBOW
E—MASTER CYLINDER TO DASH ELBOW VENT TUBE
F—CARBURETOR TO AIR CLEANER VENT TUBE
G—CRANKCASE VENTILATION VALVES
H—VACUUM LINE TEE
J—CRANKCASE VENTILATION OUTLET TUBE
K—CRANKCASE VENTILATION INLET TUBE
L—DISTRIBUTOR TO VACUUM LINE TUBE
M—DISTRIBUTOR TO AIR CLEANER TUBE
N—TRANSFER TO DASH TEE VENT TUBE
P—AIR CLEANER TO DASH TEE TUBE
Q—DASH TEE

RA PD 183851

Figure 161. Ventilating system for deep-water fording.

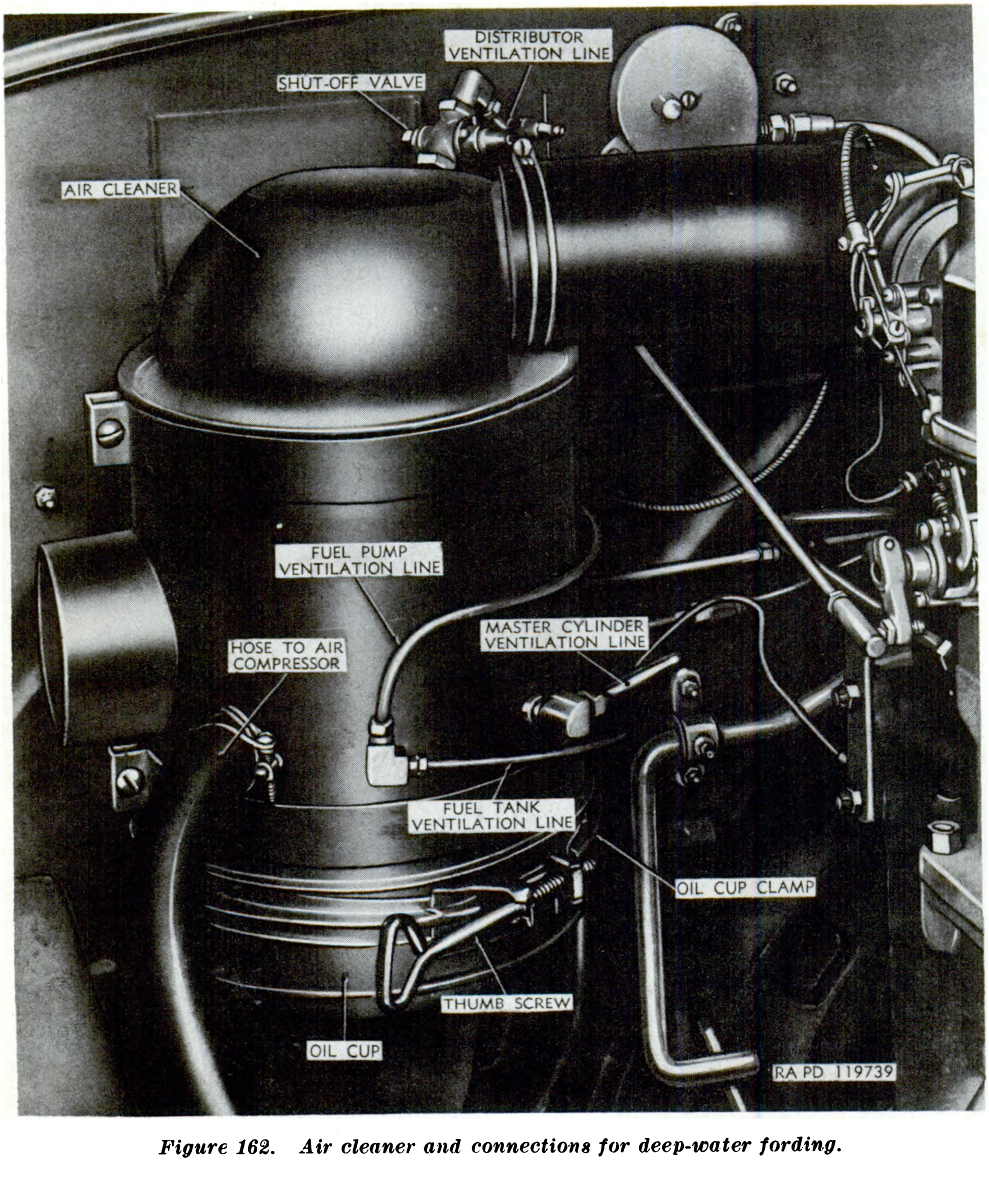

DISTRIBUTOR VENTILATION LINE
SHUT-OFF VALVE
AIR CLEANER
FUEL PUMP VENTILATION LINE
MASTER CYLINDER VENTILATION LINE
HOSE TO AIR COMPRESSOR
FUEL TANK VENTILATION LINE
OIL CUP CLAMP
THUMB SCREW
OIL CUP
RA PD 119739

Figure 162. Air cleaner and connections for deep-water fording.

PART THREE

ELECTRICAL SYSTEMS AND RELATED UNITS

CHAPTER 10

ELECTRICAL SYSTEMS

Section I. BASIC PRINCIPLES OF ELECTRICITY

110. Composition of Electricity

Scientists tell us that everything in the world is, in essence, made up of electrical charges. There are two types of these charges, which have been arbitrarily called *negative* charges and *positive* charges. When these charges begin to concentrate in one place, or to move about, we call this *electricity*, *electrical flow*, or *electrical current*. There is still much that scientists do not know about electricity, but their findings make it much easier for all of us to understand what electricity is and how it does its various jobs. On automotive equipment, for example, electricity is used for lighting, operates the starter to start the engine, produces high-voltage sparks at the engine spark plugs, operates various gages, electric fuel pumps, auxiliary motors, heaters, radio, solenoids, controls of different types, etc.

111. Composition of Matter

a. To understand electricity, let us first study matter, which is the name for all material substances. We find, if we study the world about us, that everything (solids, liquids, and gases) is made up of tiny particles called *atoms*. These atoms combine in small groups of two or more to form *molecules*. The composition of air is formed of molecules (par. 4). These molecules are made up of atoms, and these atoms can be further subdivided. When we divide atoms, we get smaller particles, some of which have positive and others negative electrical charges. Let us examine atoms of different materials to learn more about these charges.

b. There are over 100 different basic materials in the universe. These basic materials are called *elements*. Iron is one element, copper, aluminum, oxygen, hydrogen, mercury, etc. are other elements. An element gets its name from the fact that it cannot easily be broken down into simpler (or more elemental) substances. In other words, these more than 100 basic elements are the building materials from which the universe is made. But, strangely enough, if we take any one of these elements and study it closely, we find that it is made up of those same basic particles having positive and negative electrical charges, as mentioned in *a* above.

c. The basic particles that go to make up all the elements, and thus all the universe, are called *protons*, *electrons*, and *neutrons*. A proton is a basic particle having a single positive charge. An electron is a basic particle having a single negative charge. A neutron is a basic particle having no charge. A group of protons produces a positive electrical charge. A group of electrons produces a negative electrical charge. A group of neutrons would have no charge.

d. Let us examine more closely the construction of atoms of the various elements, starting with the simplest of all, hydrogen (A, fig. 163). The atom of hydrogen consists of one proton around which is circling one electron. There is an attraction between the two particles, since negative and positive electrical charges always attract each other. Opposing the attraction between the two particles, and thus preventing the electron from moving in to the proton, is the centrifugal force on the electron caused by its circular path around the proton. This is the same sort of balance we get if we were to whirl a ball tied to a string around our head. The centrifugal force exerted tries to move the ball out of its circular path, and is balanced by

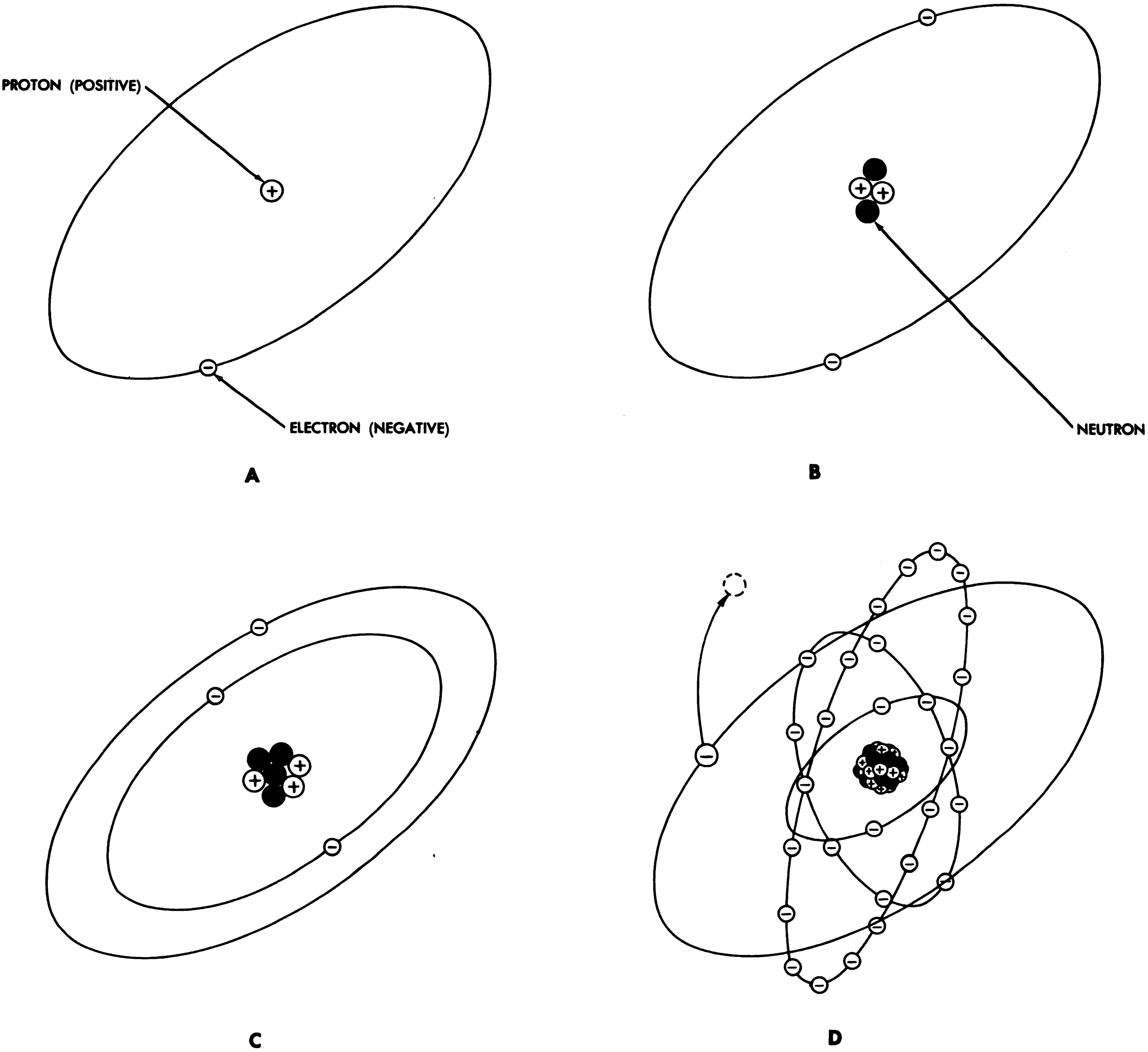


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Figure 163. Atoms of hydrogen, helium, lithium, and copper.

the string (the attractive force). If the string should break, the centrifugal force would cause the ball to fly away. Actually, this is what happens at times with atoms. The "string," that is, attractive force, between the electron and proton sometimes is not great enough to hold the electron in its circular path, and the electron gets away.

e. A slightly more complex atom is shown in B, figure 163. This is an atom of helium. Notice that there are now two protons in the center and that two electrons are circling around the center. Since there is an additional proton in the center, or nucleus, of the atom, an electron must be added so as to keep the atom in electrical balance. Notice also that there are two additional particles in the nucleus, neutrons. These two additional particles are necessary in order to overcome the tendency of the two protons to move apart from each other. For, just as *unlike* electrical charges *attract*, so do *like* electrical charges *repel.* Electrons repel electrons. Protons repel protons, except when neutrons are present. Neutrons have no electrical charge (some scientists think they are actually an electron and a proton combined in perfect electrical balance), but neutrons have the ability to cancel out the repelling forces between protons in an atomic nucleus and thus hold the nucleus together.

f. A still more complex atom is shown in C, figure 163. This is an atom of lithium, a light, soft metal. Notice that a third proton has been added to the nucleus and that a third electron is now circling around the nucleus. Notice also that there are two additional neutrons in the nucleus; these are needed to hold the three protons together. We could also picture the atoms of other elements in a similar manner. As we did so, we would find that as we go up the scale in atomic complexity, we find protons and neutrons added one by one, to the nucleus, and electrons to the outer circles. After lithium comes beryllium with 4 protons and 5 neutrons, boron with 5 protons and 5 neutrons, carbon with 6 and 6, nitrogen with 7 and 7, oxygen with 8 and 8, etc. In each of these, there are normally the same number of electrons circling the nucleus as there are protons in the nucleus.

112. Electron Theory of Electricity

We have mentioned that electrons occasionally break free of their atoms (par. 111*d*). When numerous electrons do this and gather in one area, we call the effect a *charge of electricity.* When the electrons begin to move in one direction (as along a wire, for example), we call the effect a *flow of electricity*, or an *electric current.* Actually, electric generators and batteries could be called electron pumps, since they remove electrons from one part of an electric circuit and concentrate them in another part of the circuit. For example, a generator takes electrons away from the positive terminal and concentrates them at the negative terminal. Since the electrons repel each other (like electrical charges repel), the electrons push out through the circuit and flow to the positive terminal (unlike electrical charges attract). Thus, we can see that an electric current is actually a flow of electrons from *negative to positive.*

Note. This is just the reverse of the old idea of current flow. Before scientists understood what electric current was, they assumed that the current flowed from positive to negative. However, their studies showed that this was wrong, since they learned that the current is electron movement from negative (concentration of electrons) to positive (lack of electrons).

113. Conductors and Insulators

a. The electrons, in order to flow, must have a path or circuit to move in. Copper wire forms a good circuit because it has many free electrons in it. In D, figure 163, is shown an atom of copper. It has 29 electrons circling about its nucleus in four different orbits, or paths. The outer orbit has but one electron. This electron is not held very strongly and it can get away from the nucleus rather easily. As a result, it can become a free electron. In a copper wire, made up of countless copper atoms, there are tremendous numbers of these free electrons. Thus, when a copper wire is connected to a generator, the free electrons on the negative terminal can easily push into the copper wire. As they do this, they repel free electrons farther along in the wire (like repels like). These electrons then repel other electrons ahead of them, and so on along the wire. Almost instantly, as the wire is connected, free electrons are pushed along the wire, and the free electrons in the wire at the positive terminal are pushed off and also attracted into the positive terminal.

b. An insulator is made up of a substance that does not have many free electrons. Without free electrons, a flow of electrons cannot be set up, for the flow depends upon repelling free electrons along the circuit. If an insulator blocks the circuit, free electrons cannot push through. Insulators are used to cover and protect wires and other metal parts of electrical devices. The insulators keep the free electrons (or current) from going off in the wrong direction ("wandering") and taking a short circuit. For instance, the insulation on the cord and switch of a lamp keeps the current from wandering into the hand of a person turning the lamp on and giving him an electric shock. It also prevents the current from taking a short circuit instead of going through the lamp. Insulators include rubber, porcelain, glass, certain kinds of enamel, and varnish (baked or air-dried on wire, for instance), bakelite, fiberboard of certain types, etc.

114. Amperage and Voltage

a. Current flow, or electron flow, is measured in amperes. While we normally consider that one ampere is a rather small current of electricity (it is about what a 100-watt light bulb would draw), it is actually a tremendous flow of electrons. More than 6 billion billion electrons a second are required to make up one ampere.

b. Electrons are caused to flow by a difference in electron balance in a circuit; that is, when there are more electrons in one part of a circuit than in another, the electrons move from the area where they are concentrated to the area where they are lacking. This difference in electron concentration is called *potential difference*, or *voltage*. The higher the voltage goes, the greater the electron unbalance becomes. The greater this electron unbalance, the harder the push on the electrons (more electrons repelling each other) and the greater the current of electrons in the circuit. When there are many electrons concentrated at the negative terminal of a generator (with a corresponding lack of electrons at the positive terminal), there is a much stronger repelling force on the electrons and, consequently, many more electrons moving in the wire. This is exactly the same as saying that the higher the voltage, the more electric current will flow in a circuit, all other things, such as resistance (par. 115), being equal.

115. Resistance

a. Even though a copper wire will conduct electricity with relative ease, it still offers resistance to the flow. It takes force (or voltage) to move the electrons along the wire. This resistance to electron (or current) flow is expressed in *ohms*. The resistance of a wire varies according to its length, its cross-sectional area, or diameter, its composition, and its temperature.

b. A long wire offers more resistance than a short wire of the same cross-sectional area. The electrons have farther to travel.

c. A small wire (in thickness or cross-sectional area) offers more resistance than a large wire. In the small wire, there are fewer free electrons (because fewer atoms), and thus fewer electrons can push through.

d. Some elements can lose electrons more readily than other elements. Copper loses electrons easily, so there are always many free electrons in a copper wire. Other elements, such as iron, do not lose their electrons quite as easily, so there are fewer free electrons in an iron wire (comparing it to a copper wire of the same size). Thus, with fewer free electrons, fewer electrons can push through an iron wire; that is, the iron wire has more resistance than the copper wire.

e. Most metals show an increase in resistance with an increase in temperature, while most nonmetals show a decrease in resistance with an increase in temperature. For example, glass (a nonmetal) is an excellent insulator at room temperature but is a very poor insulator when heated to red heat.

116. Ohm's Law

a. The general statements about voltage, amperage, and ohms (pars. 114 and 115) can all be related in a statement known as *Ohm's law*, so named for the scientist (Georg Simon Ohm) who first stated the relationship. This law says that *voltage is equal to amperage times ohms*. Or, it can be stated as the mathematical formula:

$$E = I \times R$$

where E is volts, I is current in amperes, and R is resistance in ohms.

b. This formula is a valuable one to remember because it makes understandable many of the things that happen in an electric circuit. For instance, if the voltage remains constant, the current flow goes down if the resistance goes up. An example of this would be the lighting circuit that is going bad in a truck. Suppose the wiring circuit between the battery and the lights has deteriorated due to connections becoming poor, strands in the wire breaking, switch contacts becoming dirty, etc. All of these conditions reduce the electron path or, in other words, increase resistance. And, with this increased resistance, less current will flow. The voltage of the battery stays the same (for example, 12 volts). If the resistance of the circuit when new (including light bulbs) was 6 ohms, then 2 amperes will flow. To satisfy the equation, 12 (volts) must equal 12 (amperes times ohms resistance). But if the resistance goes up to 8 ohms, only 1.5 amperes can flow. The increased resistance cuts down the current flow and consequently the amount of light.

c. A great majority of electrical troubles on automotive vehicles result from increased resistance in circuits due to bad connections, deteriorated wiring, dirty or burned contacts in switches, etc. With any of these conditions, the resistance of the circuit goes up and the ampere flow through that circuit goes down. Bad contact points in the ignition circuit will reduce current flow in the circuit and cause weak sparks at the spark plugs. This will result in engine missing and loss of power.

d. If the resistance stays the same but the voltage increases, the amperage also increases. This is a condition that might occur if a generator voltage regulator became defective. In such a case, there would be nothing to hold the generator voltage within limits, and the voltage might increase excessively. This would force excessive amounts of current through various circuits and cause

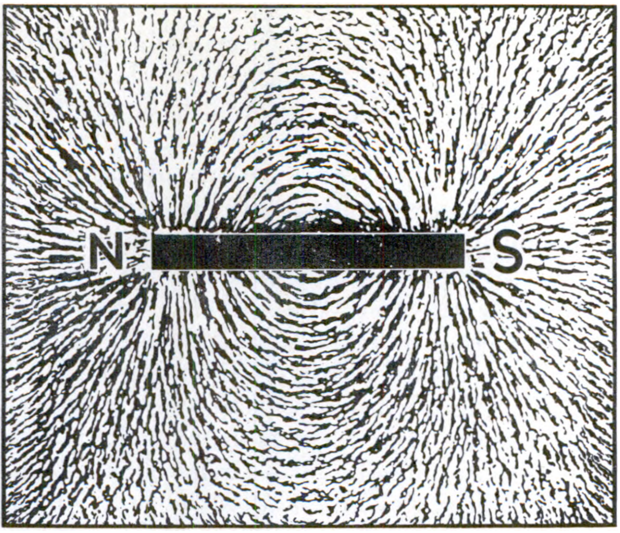

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Figure 164. Magnetic lines of force of a bar magnet as shown by iron filings.

serious damage. If too much current went through the lightbulb filaments, for example, the filaments would overheat and burn out. Also, other electrical devices probably would be damaged.

e. On the other hand, if the voltage is reduced, the amount of current flowing in a circuit will also be reduced if the resistance stays the same. For example, with a run-down battery, battery voltage will drop excessively with a heavy discharge. When trying to start an engine with a run-down battery, the voltage will drop very low. This voltage is so low that it cannot push enough current through the starter for effective starting of the engine.

117. Magnets

a. General. We have learned in paragraph 112 that electric current is a flow of electrons and that the unbalance of electrons in a circuit (that causes electrons to flow) is called *voltage.* As a first step in learning what causes a generator to concentrate electrons at the negative terminal and take them away from the positive terminal, magnets will be studied.

b. Magnetic Field. If we were to take a bar magnet, lay a piece of glass on top of it, and then sprinkle iron filing on the glass, we would find that the filings would become arranged in curved lines (fig. 164). These curved lines, extending from the two poles of the magnet (north and south), follow the *magnetic lines of force* surrounding the magnet. Scientists cannot fully explain magnetism, but they have formulated certain rules for these lines of force. These rules are listed in (1) through (6) below.

(1) The lines of force (outside the magnet) pass from the north to the south pole of the magnet.

(2) The lines of force act somewhat as rubber bands and try to shorten to a minimum length.

(3) The lines of force repel each other along their entire length and so try to push each other apart.

(4) The "rubber-band" characteristic opposes the "push-apart" characteristic.

(5) The lines of force never cross each other.

(6) The magnetic lines of force, taken together, are referred to as the *magnetic field* of the magnet.

c. Bar and Horseshoe Magnets. The magnetic fields of a bar and of a horseshoe magnet are shown in figure 165. In each, note how the lines of force curve and pass from the north to the south pole.

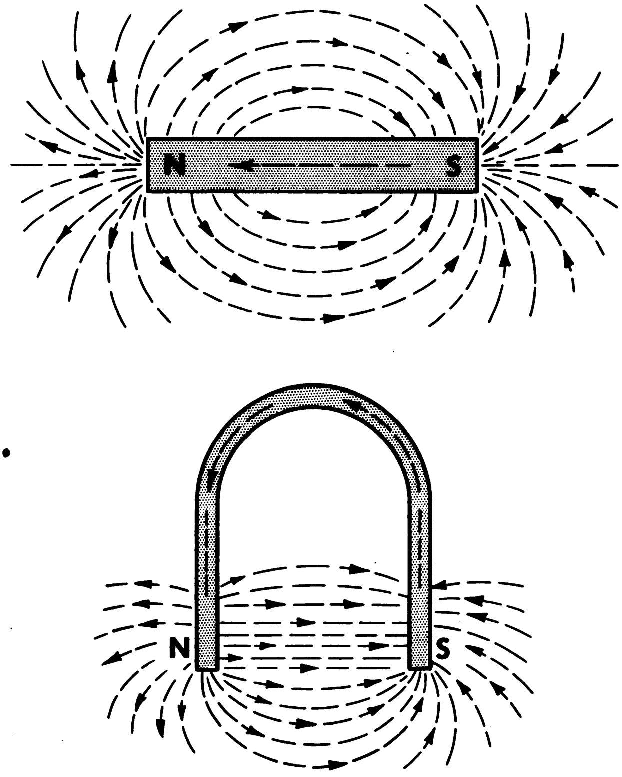

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Figure 165. Magnetic fields of a bar and of a horseshoe magnet.

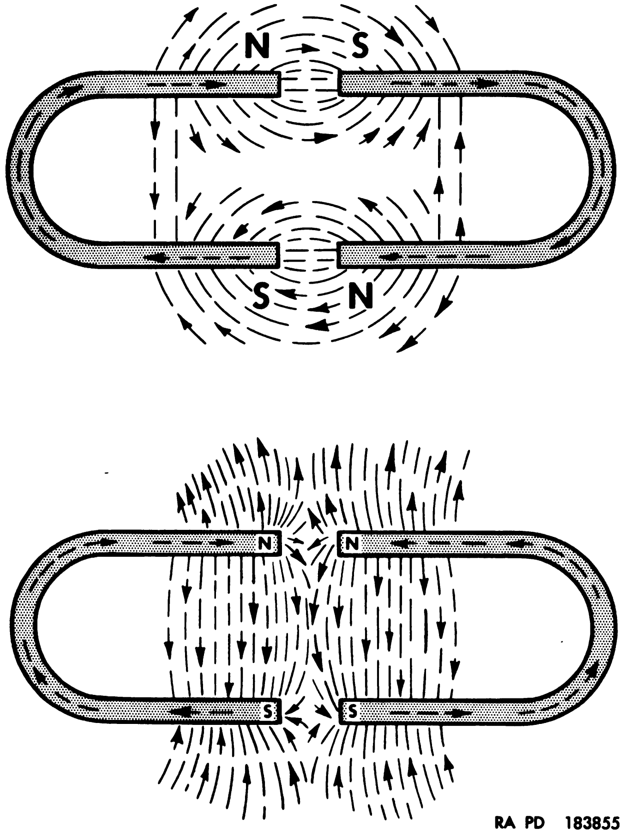

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Figure 166. Attraction and repulsion between magnetic poles.

d. Effects Between Magnetic Poles. When two unlike magnetic poles are brought together, they attract. But when like magnetic poles are brought together, they repel. These actions can be explained in terms of the rubber-band and the push-apart characteristics (fig. 166). When unlike poles are brought close to each other, the magnetic lines of force pass from the north to the south poles. They try to shorten (like rubber bands), and therefore try to pull the two poles together. On the other hand, if like poles are brought close to each other, lines of force going in the same direction are brought near each other. Since these lines of force attempt to push apart, a repelling effect results between the like poles.

118. Electromagnetism

a. An electric current (flow of electrons) always produces a magnetic field. In the wire shown in figure 167, current flow causes lines of force to circle the wire. It is thought that these lines of force result from the movement of the electrons along the wire. As they move, the electrons "send out" the lines of force. When many electrons move, there are many lines of force (the magnetic field is strong). Few electrons in motion means a weak magnetic field or few lines of force.

b. Electron movement as the basis of magnetism in bar and horseshoe magnets can be explained by assuming that the atoms of iron are so lined up in the magnets that the electrons are circling in the same direction. With the electrons moving in the same direction, their individual magnetic lines of force add to produce the magnetic field.

c. The magnetic field produced by current flowing in a single loop of wire is shown in figure 168. The magnetic lines of force circle the wire (fig. 167), but here they must follow the curve of the wire. If two loops are made in the conductor, the lines of force will circle the two loops (fig. 169). In the area between the adjacent loops, the magnetic lines are going in opposite directions. In such a case, since they are of the same strength (from same amount of current traveling in both loops), they cancel each other out. The lines of force, therefore, circle the two loops almost as though they were a single loop. However, the magnetic field will be twice as strong since the lines of force of the two loops combine.

d. When many loops of wire are formed into a coil as shown in figure 170, the lines of force of

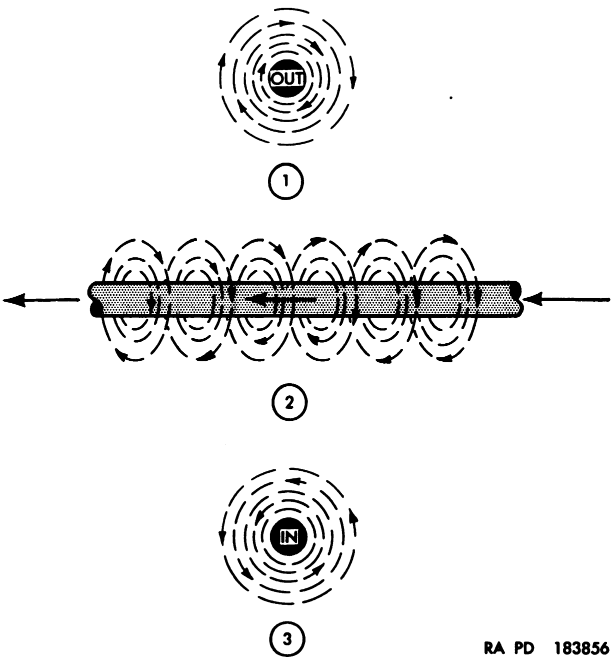

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Figure 167. Magnetic field around a wire carrying current.

all loops combine into a pattern that greatly resembles the magnetic field surrounding a bar magnet. A coil of this type is known as an *electromagnet* or a *solenoid*. However, electromagnets can be in many shapes. The field coils of generators and starters, the primary winding in an ignition coil, the coils in electric gages, even the windings in a starter armature, can be considered to be electromagnets. All of these produce magnetism by electrical means, as discussed in paragraph 119.

e. The north pole of an electromagnet can be determined, if the direction of current flow (from negative to positive) is known, by use of the left-handed rule, (fig. 171). The left hand is held around the coil with the fingers pointing in the direction of current flow. The thumb will point to the north pole of the electromagnet. This rule is based on current, or electron, flow from *negative*

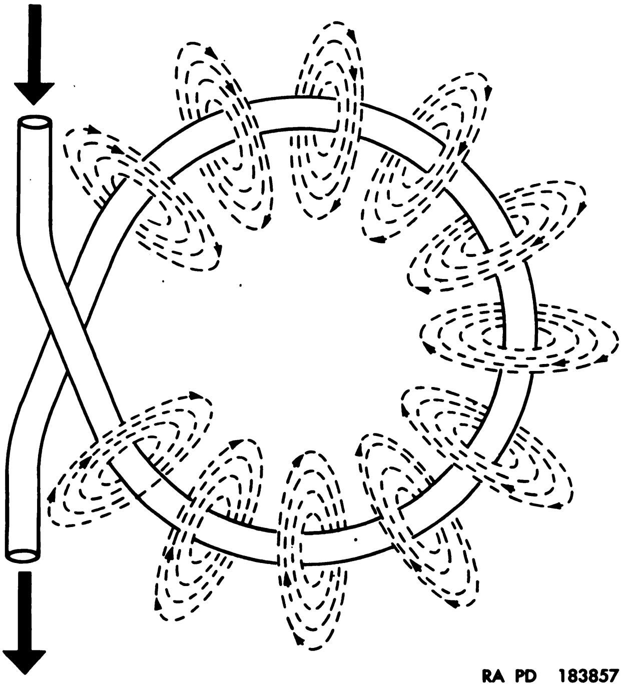
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Figure 168. Magnetic field in loop of wire carrying current.

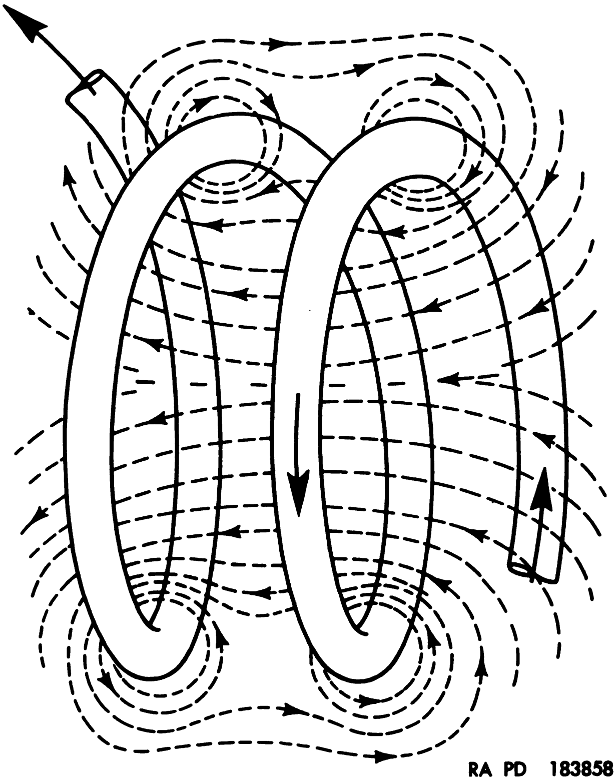
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Figure 169. Magnetic field in two adjoining loops of wire carrying current.

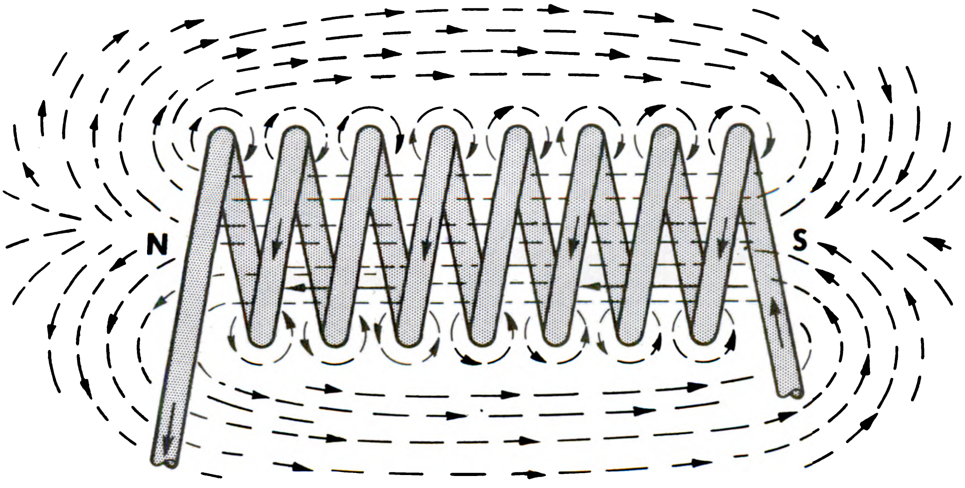

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Figure 170. Magnetic field produced by current flowing in an electromagnet.

to positive. Before the true nature of electricity was discovered, it was assumed that current flowed from positive to negative. With this idea in mind, scientists formulated a *right-handed* rule for determining the north pole of an electromagnet. However, after it had been learned that the current is actually from negative to positive, the rule was changed to the *left-handed* rule.

f. The left-handed rule can also be used to determine the direction that lines of force circle a wire carrying current, if the direction of current is known. This is done by circling the wire with the left hand and with the thumb pointing in the direction of current flow (negative to positive). The fingers will then point in the direction that the magnetic field circles the wire. Try this with figure 167.

g. The strength of an electromagnet can be greatly increased by wrapping the loops of wire around an iron core. The iron core passes the lines of force with much greater ease than air. This property of permitting lines of force to pass through easily is called *permeability.* Wrought iron is 3,000 times more permeable than air. In other words, it allows 3,000 times as many lines of force to get through. With this great increase in the number of lines of force, the magnetic strength of the electromagnet is greatly increased, even though no more current flows through it. Practically all electromagnets use an iron core of some kind.

119. Electromagnetic Induction

a. Current can be induced to flow in a conductor if it is moved through a magnetic field. In figure 172, the wire is moved downward through the magnetic field between the two magnetic poles. As it moves downward, cutting lines of force, current is induced in it. The reason for this is that the lines of force resist cutting, and tend to wrap around the wire as shown. With lines of force wrapping around the wire, current is induced. The wire movement through the magnetic field produces a magnetic "whirl" around the wire, which pushes the electrons along in the wire.

b. If the wire is held stationary and the magnetic field is moved, the effect is the same; that is, current will be induced in the wire. All that is required is that there be relative movement between the two so that lines of force are cut by the wire. It is this cutting and whirling, or wrapping, of the lines of force around the wire that produces the current movement in the wire.

c. The magnetic field can be moved by moving the magnet or, if it is a magnetic field from an electromagnet, it can be moved by starting and stopping the current flow in the electromagnet. Suppose we had an electromagnet such as the one shown in figure 170, and held a wire close to it. When we connected the electromagnet to a battery, current would start to flow through it. This current, as it starts to flow, builds up a magnetic

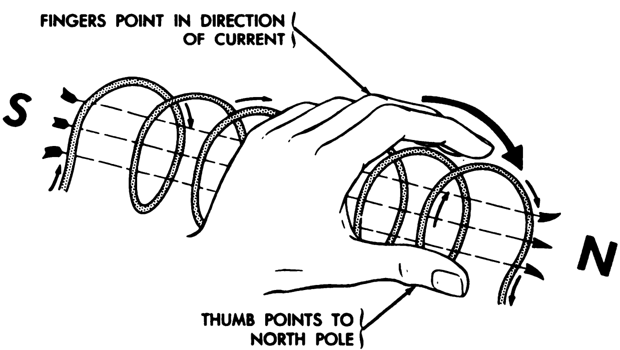
FINGERS POINT IN DIRECTION OF CURRENT
S
N
THUMB POINTS TO NORTH POLE

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Figure 171. Using left-hand rule to determine polarity of an electromagnet.

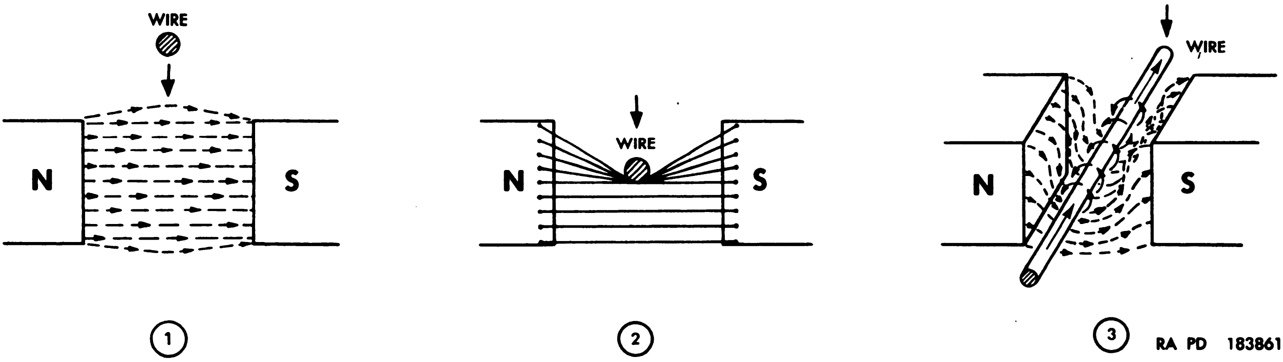

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Figure 172. Current induced by electromagnetic induction.

field. In other words, a magnetic field forms because of the current flow. This magnetic field might be considered as expanding (like a balloon, in a sense) and moving out from the electromagnet. As it moves outward, its lines of force will cut through the wire held close to the electromagnet. This wire will therefore have current induced in it. The current will result from the lines of force cutting across the wire. If the electromagnet is disconnected from the battery, its magnetic field will collapse and disappear. As this happens, the lines of force move inward toward the electromagnet. Again, the wire held close to the electromagnet will be cut by moving lines of force and will have a current induced in it. This time, the lines of force are moving in the opposite direction and the wire will, therefore, have current induced in it in the opposite direction.

d. It can thus be seen that current can be induced in the wire by three methods: the wire can be moved through the stationary magnetic field, the wire can be held stationary and the magnet can be moved so the field is carried past the wire, or the wire and electromagnet can both be held stationary and the current turned on and off to cause the magnetic field buildup and collapse, so the magnetic field moves one way or the other across the wire.

Section II. BATTERY

120. General

The storage battery provides electrical energy through chemical reactions. When a generator in the electrical system of a motor vehicle produces more electrical energy than required for ignition and for operating electrical accessories, the surplus (under certain conditions) passes through the battery to reverse the chemical reaction. This is known as *charging* the battery. When the generator is not producing the necessary electrical energy, the battery can, through chemical reaction, supply the energy required in the electrical system of the vehicle. The battery is then said to be *discharging.*

121. Construction

The storage battery, as used for starting, lighting, and ignition purposes, consists of three or more cells, depending on the voltage desired. A battery of three cells (2 volts each) connected in series is known as a 6-volt battery, and one of six cells connected in series is known as a 12-volt battery. Typical battery construction is shown in figure 173.

a. Plates.

(1) Each cell consists of a hard rubber jar or compartment into which are placed two kinds of lead plates, known as *positive* and *negative.* These plates are insulated from each other by suitable separators and are submerged in a sulfuric acid solution.

(2) The backbone of both the positive and negative plates is a grid made of stiff lead alloy casting. The grid, usually composed of vertical and horizontal cross members, is carefully designed to give the plates mechanical strength and, at the same time, to provide adequate conductivity for the electric current created by the chemical action. The active material, composed chiefly of lead oxides, is ap-

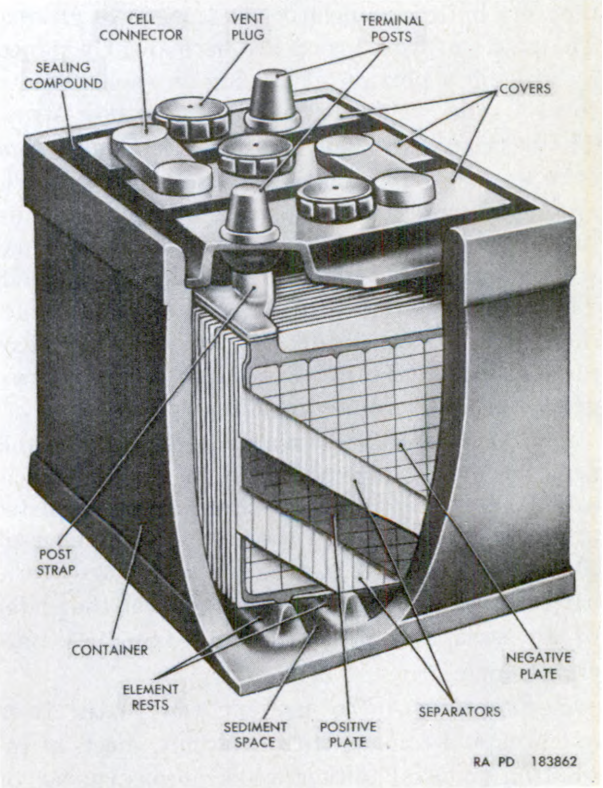


Figure 173. Storage battery with case partially cut away to show cell construction.

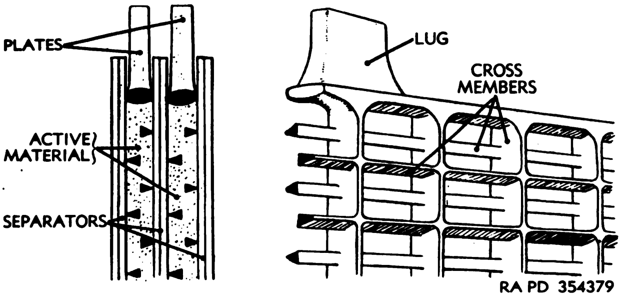


Figure 174. Section of battery plate grid with cross section showing active material in place.

plied to the grids in paste form, then allowed to dry and harden, like cement. Part of a grid is shown in figure 174, with a cross section showing the active material in place The plates are then put through an electrochemical process that converts the hardened active material of the positive plates into brown lead peroxide, and that of the negative plates into gray, spongy, metallic lead. Plates that have been put through this process, known as *forming* the plates, are shown in figure 175(1) and (2).

b. Groups. After the plates have been formed, they are built into positive and negative groups. The plates of each group are permanently joined by melting a portion of the lug on each plate to form a solid weld with a connecting post strap. The heat necessary for this process, termed *lead burning*, is produced by a gas flame or an electric arc. The connecting post strap to which the plate lugs are burned contains a cylindrical terminal which forms the outside connection for the cell. The negative group of plates has one more plate than the positive group, to provide a negative plate on both sides of all positive plates. These groups are shown in figure 175.

c. Elements. The assembly of a positive and negative group, together with the separators, is called an *element.* Since storage battery plates are more or less of standard size, the number of plates in an element is, roughly, a measure of the battery capacity. The distance between the plates of an assembled element is approximately one-eighth inch.

d. Separators. To prevent the plates from touching and causing a short circuit, sheets of insulating material (either wood, porous rubber, or spun glass), called *separators*, are inserted between the plates. These separators (fig. 175(3)) are thin and porous so the electrolyte will flow easily between the plates. One side of the separator (that placed against the positive plate) is grooved, so the gas that forms during charging will rise to the surface more readily. These grooves also provide room for any material that flakes from the plates to drop to the sediment space below.

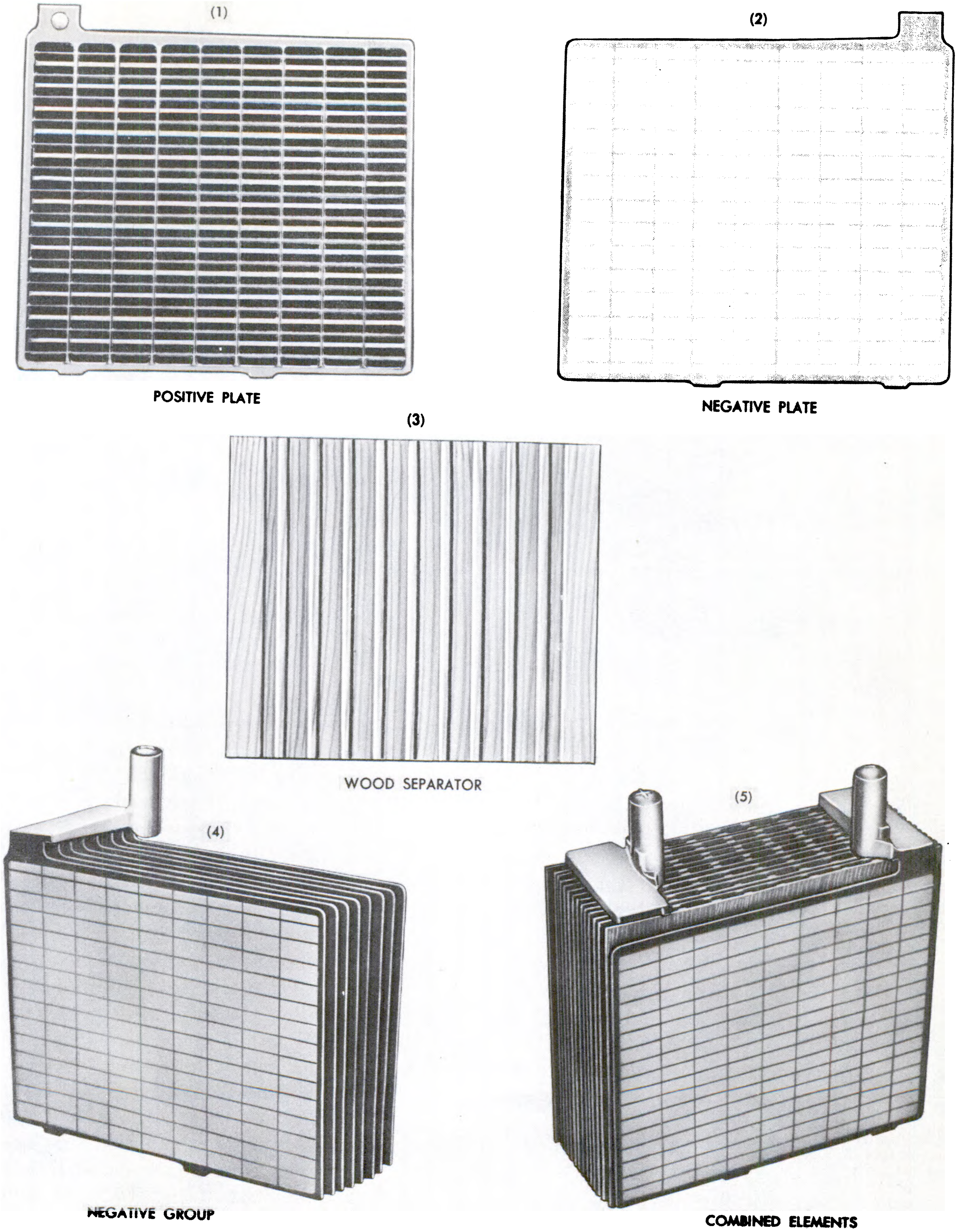
e. Electrolyte.

(1) *Composition.* An electrolyte is a liquid which readily conducts electricity and is decomposed when an electric current passes through it. The electrolyte in the lead-acid storage battery has a specific gravity of 1.280, and is composed of one part of chemically pure sulfuric acid (H_2SO_4) and approximately two and three-fourths parts, by volume, of distilled water. (A small quantity of some impurity introduced into the acid solution by using impure water might interfere with the chemical action and cause battery trouble.)

(2) *Specific gravity readings.* Specific gravity is the ratio of the weight of a substance to weight of the same volume of chemically pure water at 4° C. (39.2° F.). The specific gravity of sulfuric acid is 1.835; that is, sulfuric acid is 1.835 times heavier than water. The electrolyte of a storage battery is a mixture of water and sulfuric acid. The amount of sulfuric acid in the electrolyte changes with the amount of electrical charge; also, the specific gravity of the electrolyte changes with the amount of electrical charge. This provides a convenient way of measuring the degree of charge in a battery.

(3) *Hydrometer.*

(*a*) Specific gravity of the electrolyte can be measured by a hydrometer (fig. 176). A reading is taken by drawing sufficient electrolyte into the hydrometer to cause the float within the glass tube to float. For convenience, the readings are spoken of as being 1,150, 1,200, 1,280, etc., instead of 1.15, 1.2, 1.28, etc., the true specific gravities. The electrolyte is returned to the cell by compressing the bulb, and the reading of the next cell can then be taken.


(1)
POSITIVE PLATE
(2)
NEGATIVE PLATE
(3)
WOOD SEPARATOR
(4)
NEGATIVE GROUP
(5)
COMBINED ELEMENTS

RA PD 183863

Figure 175. Storage battery plate grid, plate, separator, plate group, and element.

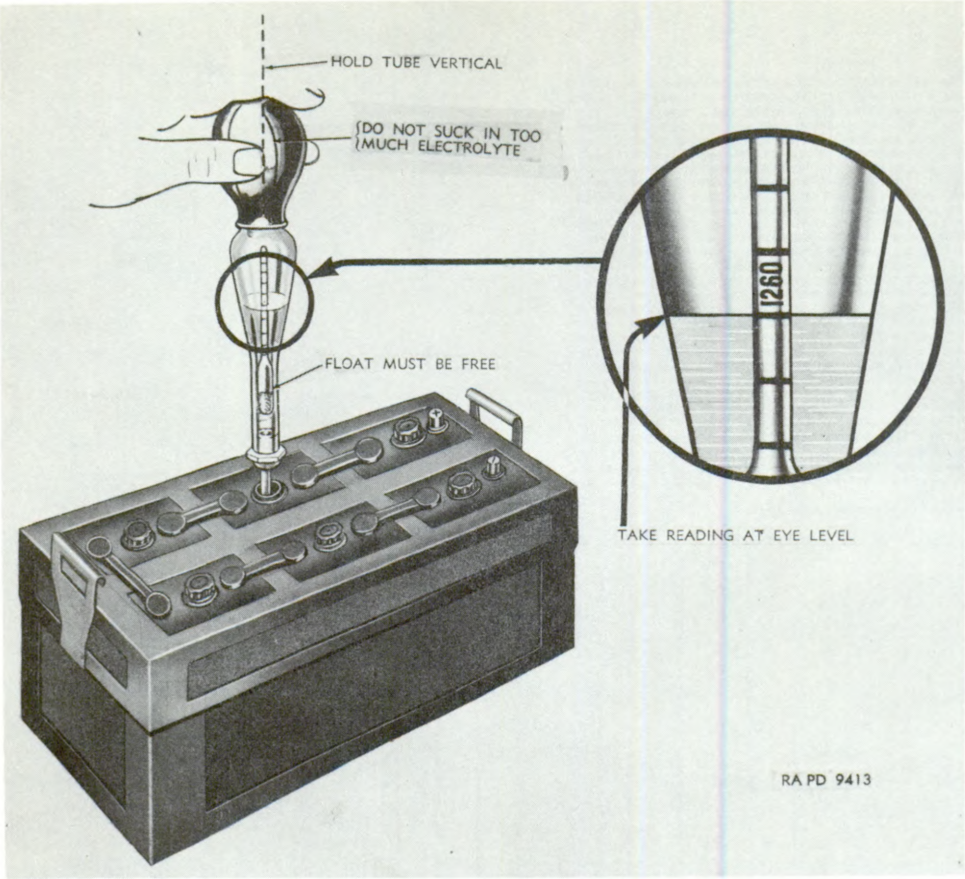

HOLD TUBE VERTICAL
DO NOT SUCK IN TOO MUCH ELECTROLYTE
FLOAT MUST BE FREE
1260
TAKE READING AT EYE LEVEL
RA PD 9413

Figure 176. Taking specific gravity reading of a battery with hydrometer.

(*b*) Specific gravity readings of from 1,270 to 1,285 indicate that the battery is fully charged. Readings between 1,200 and 1,215 indicate that the battery is more than half discharged, and that starter and accessories should be used sparingly until the battery is again fully charged. Readings between 1,125 and 1,140 indicate that the battery is nearing a discharged condition and immediate charging is necessary; otherwise, serious damage will result.

(4) *Temperature correction.* All hydrometer readings given are usually based on the normal temperature of 80° F. for the electrolyte. This refers to the temperature of the liquid itself and not to the temperature of the surrounding atmosphere. To make temperature correction, add 1 to the hydrometer reading for every 2.5° above 80° F., and subtract 1 for every 2.5° below 80° F. (fig. 177). For example, if the reading is 1,250 at 100° F., add 8 to give a corrected reading of 1,258. If the reading is 1,270 at 20° F., subtract 24 to give a corrected reading of 1,246. Some storage battery manufacturers use other than 80° F. as a base for temperature correction. It is usually unnecessary to make allowance for temperature variations, but it is well to bear them in mind; otherwise, the hydrometer reading will be misleading.

(5) *Tropical operation.*

(*a*) When batteries are operated in tropical climates, the full-charge specific gravity should be reduced to a value between 1.200 and 1.225 by dilution with water. (Rain water may be used if distilled water is not available.)

(*b*) At the high temperature encountered in the tropics, the acid in the electrolyte is more active and a weaker concentration will give satisfactory re-

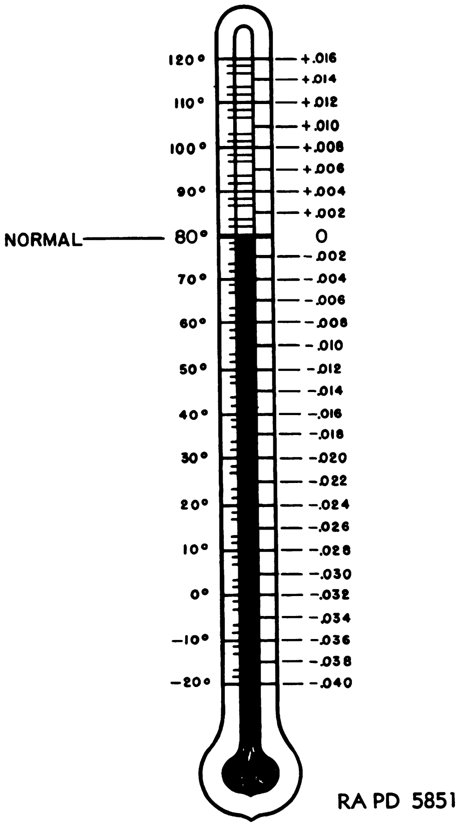


Figure 177. Hydrometer temperature correction chart.

sults with less damage to plates and separators.

(*c*) When the electrolyte is diluted, a tag indicating the full-charge specific gravity should be attached to the battery. These batteries should also be identified by painting all the connectors white. Be careful to readjust the specific gravity before shipping such batteries to frigid areas.

f. Container.

(1) A battery container is a receptacle for the cells that make up the battery. It is made of hard rubber or a composition material which is resistant to acid and mechanical shock. Most motor vehicle batteries are assembled in a one-piece container (fig. 178) with three or six compartments for the individual cells. One element and enough electrolyte to cover the plates are inserted into each cell compartment.

(2) Stiff ridges, or ribs, molded in the bottom of the container, form a support for the plates and a sediment recess for the flakes of active material that drop off the plates during the life of the battery. The sediment is thus kept clear of the plates so it will not cause a short circuit across them.

g. Cover. A hard rubber cell cover (B, fig. 179), provided with openings for the two terminals of the element and a vent plug, is placed on each cell. The cells are then sealed with pitchlike compound and connected in series by burning cell connectors on the terminals. The vent plug allows accumulated gas to escape and prevents the electrolyte from splashing outside the battery. Checking and filling the battery can be done by unscrewing the vent plug.

122. Principle of Operation

When a cell is fully charged, the negative plate is spongy lead, the positive plate is lead peroxide, and the electrolyte contains a maximum amount of sulfuric acid. Both the negative and positive plates are very porous and are readily acted upon by the acid. A cell in this condition can produce electrical energy through reaction of the chemicals.

a. Discharge. If the terminals of the battery are connected to a closed circuit, the cell discharges to supply electric current (fig. 180). The chemical process that occurs during discharge changes both the lead (Pb) of the negative plate and the lead peroxide (PbO_2) of the positive plate to lead sulfate ($PbSO_4$) and the sulfuric acid (H_2SO_4) to water (H_2O). Thus, the electrolyte becomes weaker during discharge, since the water increases and the sulfuric acid decreases. As the discharge progresses, the negative and the positive plates finally contain considerable lead sulfate. The discharge should always be stopped before the plates have entirely changed to lead sulfate.

b. Charge.

(1) *Chemical Action.* To charge the cell, an external source of direct current must be connected to the battery terminals. The chemical reaction is then reversed and returns the positive and negative plates and the electrolyte to their original condition. When all the sulfate (SO_4) on the plates has been returned to the electrolyte to form sulfuric acid (H_2SO_4), the cell is fully recharged and ready to be used for the next discharge. Charging must be started before both

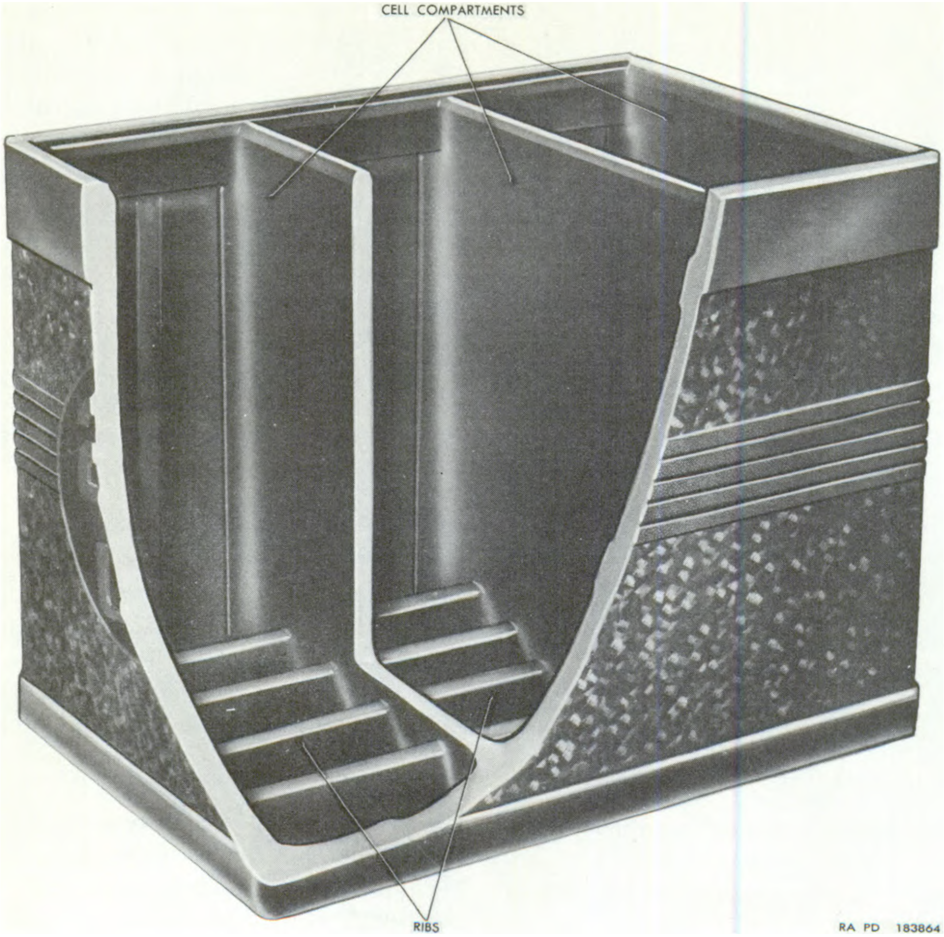
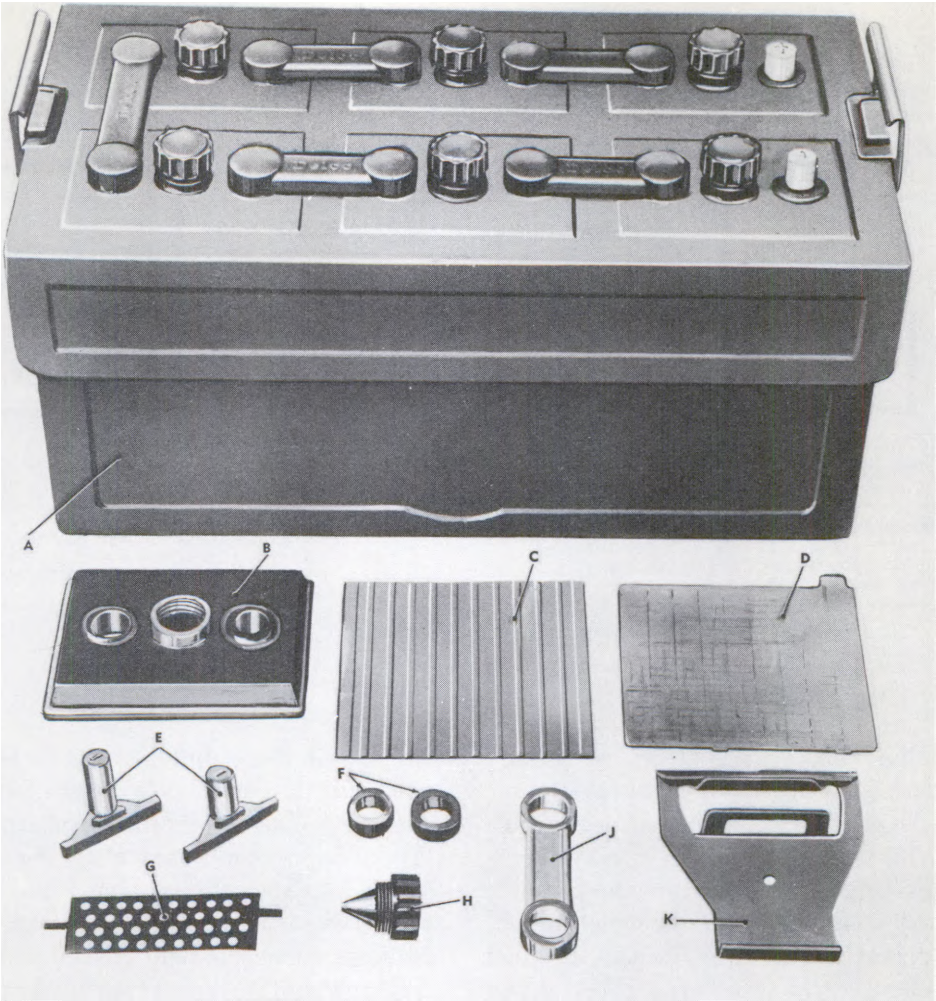


Figure 178. One-piece battery container having three cell compartments.

plates have become entirely sulfated. If this is not done, the plate surfaces are no longer chemically different and therefore will not respond to the charging current, since two dissimilar plates must be in the electrolyte to produce the action. The chemical processes in the cell during discharge and charge can be followed from figure 180.

(2) *Electrical.* A storage battery can be charged by direct current only. If only alternating current is available, a motor-generator set or a rectifier must be used to convert it into direct current. In charging, the positive wire of the charging circuit must always be connected to the positive (+) terminal of the battery and the negative wire to the negative (−) terminal. The electrolyte in each cell should be brought to the proper level by the addition of pure water before the battery is connected for charging.

c. Capacity. All batteries are given a normal capacity rating according to the ampere-hours obtainable from the battery under certain working conditions. The capacity of a battery is the number of amperes delivered multiplied by the number of hours the battery is capable of delivering this current. One of the inherent characteristics of a storage battery is that its ampere-hour capacity depends upon the rate of discharge. A battery will give more ampere-hours at a long, low, or intermittent discharge rate than at a short, high, or continuous discharge rate. This is because the voltage drops relatively faster at higher rates. Like other chemical processes, that of the battery is much less efficient in cold weather than in hot weather. At 0° F., a battery has only about 40 percent of the full cranking capacity available at 80° F. In an emergency little, if any, permanent



A—CONTAINER
B—CELL COVER
C—SEPARATOR
D—PLATE
E—{TERMINAL POST AND PLATE STRAP
F—BUSHING
G—BAFFLE PLATE
H—VENT PLUG
J—CELL CONNECTOR
K—HANDLE

RA PD 349644

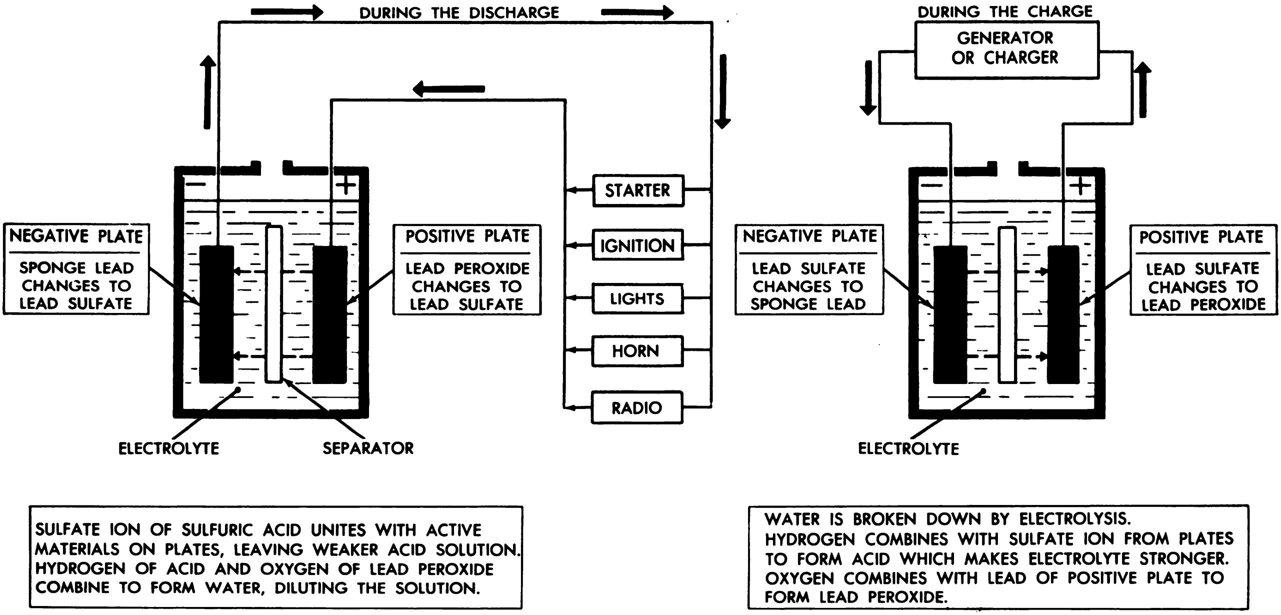
Figure 179. Battery components.

harm will result if the battery is discharged at a very high rate, provided it is promptly recharged. The battery is likely to deteriorate if left in a discharged condition.

123. Battery Charging Methods

a. General. Two methods of battery charging are in general use, constant-current and constant-potential (or voltage). By either method, the alternating current which is available in most areas is converted into direct current, since only direct current can be used for charging batteries.

b. Constant-Current Method. With the constant-current method, the battery is connected to a charging device that supplies a steady flow of current. The charging device has a rectifier (a gas-filled bulb or a series of chemical disks) that rectifies the alternating current. That is, it changes it to direct current since it permits the current to flow one way only. A rheostat of some kind is usually incorporated in the charger so that the amount of current flowing can be adjusted to suit the battery. Once the rheostat is set, the amount of current remains constant. The usual charging rate is 1 amp per positive plate per cell. That is, with a 21-plate battery (which has 10 positive plates per cell), the charging rate should be no greater than 10 amps. When using this type of charger, the service man should check the battery frequently, particularly near the end of the


DURING THE DISCHARGE
NEGATIVE PLATE
SPONGE LEAD CHANGES TO LEAD SULFATE
POSITIVE PLATE
LEAD PEROXIDE CHANGES TO LEAD SULFATE
STARTER
IGNITION
LIGHTS
HORN
RADIO
ELECTROLYTE
SEPARATOR
SULFATE ION OF SULFURIC ACID UNITES WITH ACTIVE MATERIALS ON PLATES, LEAVING WEAKER ACID SOLUTION. HYDROGEN OF ACID AND OXYGEN OF LEAD PEROXIDE COMBINE TO FORM WATER, DILUTING THE SOLUTION.
DURING THE CHARGE
GENERATOR OR CHARGER
NEGATIVE PLATE
LEAD SULFATE CHANGES TO SPONGE LEAD
POSITIVE PLATE
LEAD SULFATE CHANGES TO LEAD PEROXIDE
ELECTROLYTE
WATER IS BROKEN DOWN BY ELECTROLYSIS. HYDROGEN COMBINES WITH SULFATE ION FROM PLATES TO FORM ACID WHICH MAKES ELECTROLYTE STRONGER. OXYGEN COMBINES WITH LEAD OF POSITIVE PLATE TO FORM LEAD PEROXIDE.

RA PD 183865

Figure 180. Chemical action in a storage battery.

charging cycle. When the battery is gassing freely and there is no further rise of gravity for 2 hours, it can be assumed that the battery is fully charged.

c. Constant-Potential. The constant-potential charger usually consists of a motor-generator set. The motor drives a generator (which is much like the generator on the vehicle), and this generator produces current to charge the battery. The voltage in this type of system is usually held constant. With a constant voltage, the charging rate to a low battery will be high. But as the battery approaches a charged condition, the opposing voltage of the battery goes up (in effect), so that it more and more strongly opposes the charging current. We might say that such a battery is becoming "filled up" and thus signals, by its opposition to the charging current, that it needs a smaller charging current. As the battery approaches a charged condition, the charging voltage (which is held constant) is less and less able to maintain a charging current to the battery. As a result, the charging current tapers off to a very low value by the time the battery reaches a fully-charged condition. This is the way in which the generator and voltage regulator work on the vehicle, as described in paragraph 132 on regulators.

Section III. GENERATING SYSTEM

124. The Generator

a. Definition and Use. The generator is a machine (dynamo) in which the principle of electromagnetic induction is used to convert mechanical energy into electrical energy. The generator restores to the battery the current used in cranking the engine and it also supplies, up to the limit of its capacity, current to carry the electrical load of the lights, ignition, radio, horn, etc. A generator and a motor are fundamentally the same in construction and utilize the same electrical principles; however, their operation is opposite. In one (generator), mechanical motion is converted into electrical energy. In the other (motor), electrical energy is converted into mechanical motion.

b. Components. The generator consists essentially of an armature, a field frame, field coils, and a commutator with brushes to establish electrical contact with the rotating element. The magnetic field of the generator is usually produced by electromagnets or poles magnetized by current flowing through the field coils. Soft iron pole pieces (or pole shoes) are contained in the

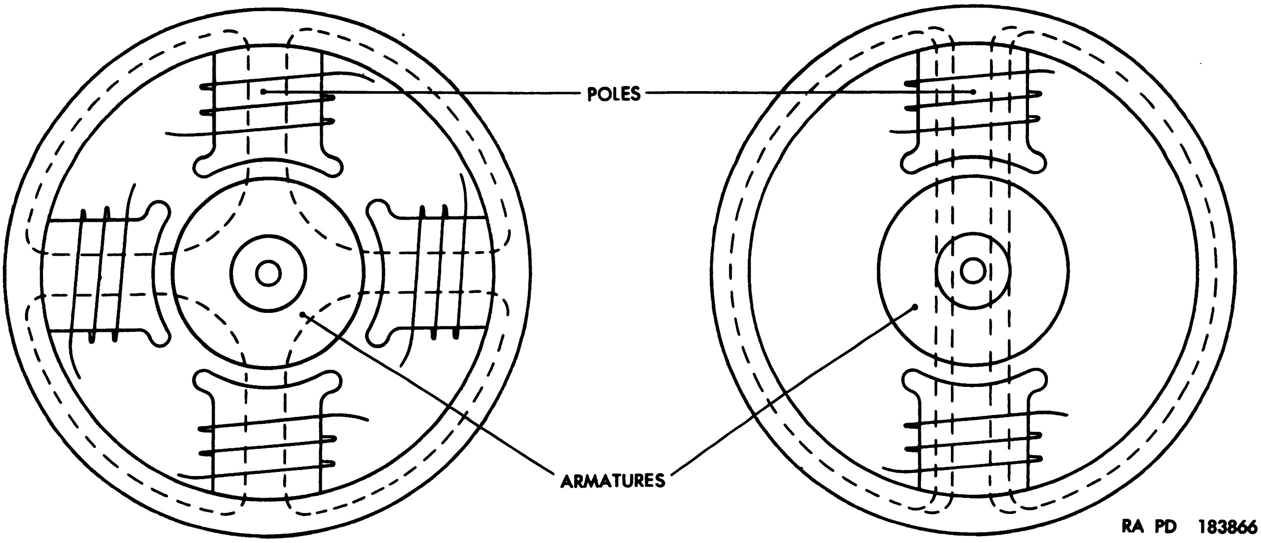


Figure 181. Two and four-pole field frames and their magnetic circuits.

field frame that forms the magnetic circuit between the poles. Although machines may be designed to have any even number of poles, 2- and 4-pole frames are the most common.

c. Field Frames. Figure 181 shows the generator field frames most commonly used and the magnetic circuits in each. In the 2-pole type frame, the magnetic circuit flows directly across the armature, while in the 4-pole type each magnetic circuit flows through only a portion of the armature core. For this reason, the armature must be constructed in accordance with the number of field poles, since current is generated when the coil, winding on the armature, moves across each magnetic circuit.

d. Brushes and Commutator. The current is collected from the armature coils by the brushes (usually made of carbon) which make rubbing contact with a commutator. The commutator consists of a series of insulated copper segments mounted on one end of the armature, each segment connecting to one or more armature coils. The armature coils are connected to the external circuit (battery, lights, ignition, etc.) through the commutator and brushes. Current induced in the armature coils is thus able to flow to the external circuit.

125. Simple Direct-Current Generator

a. Induced Current. If a single loop of wire is revolved in the magnetic field between a north pole and a south pole, there will be an electrical pressure induced in the two sides of the loop, and the voltage and current induced will be in definite relation to the direction of the magnetic field and the direction of rotation. If each end of the loop is connected to a metal segment of a commutator on which brushes rest (fig. 182), this induced electrical pressure will cause a current to flow through any external circuit which may be connected across the two brushes.

b. Commutation. If the loop is rotated through a complete revolution (fig. 182), sides A and B will cut magnetic lines of force in first one direction (fig. 182 (1)) and then in the other (fig. 182 (2)), inducing current in each side of the loop, first in one direction and then in the other. That is, in side A, current will flow in one direction when it is passing the north pole and in the other direction when it is passing the south pole. However, since the commutator segments also rotate with the loop, the current will always leave the right-handed brush (D, fig. 182) and enter the left-handed brush (C, fig. 182). The directions of induced current in each side of the loop can be determined by use of the left-handed rule, described in paragraphs 118*e*.

126. Amount of Current Induced

a. In the simple, single-loop generator (fig. 182), the current induced in each side of the loop reaches a maximum when the sides are cutting the lines of force in a perpendicular direction. This is the position in which the loop is shown. As the loop moves away from this position, it cuts fewer and fewer lines of force and less and less current

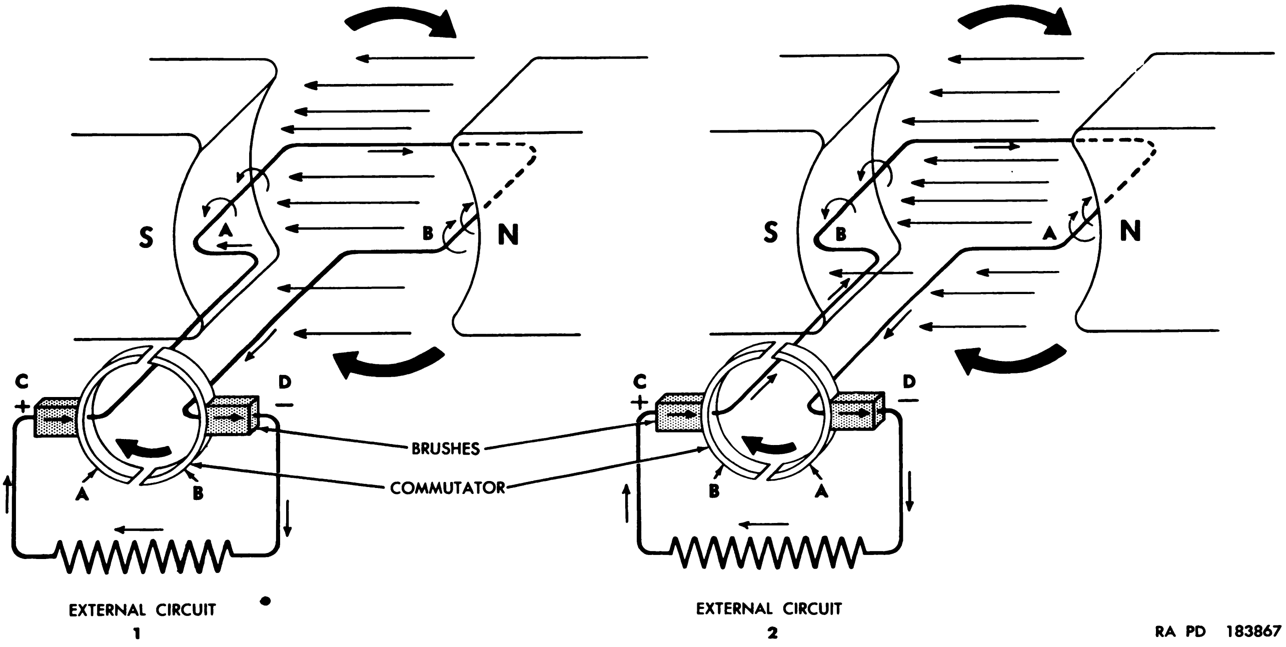


Figure 182. A simple direct-current generator.

is induced. By the time the loop has turned 90° from the position shown, the sides are moving parallel to the lines of force and are cutting no lines, therefore no current is being induced. The current induced from the single loop could be shown in graph form (fig. 183).

b. Many loops, or turns, of wire are required in the conductor in order for the generator to produce any appreciable amount of current and an even flow of current. Figure 184 shows an armature in place in a generator. Note that many turns are used in the armature windings. The windings are assembled into a soft iron core because the iron is more permeable than other substances that could be used. The windings are connected to each other and to the commutator segments in such a way that the current impulses overlap and produce a smooth flow of current. This could be compared to the overlapping of power impulses in an 8- or a 12-cylinder engine.

127. Field Windings

The purpose of the field windings (field coil) (fig. 184) is to increase the strength of the magnetic field (by their electromagnetic action) so that more current will be induced in the armature windings as the armature rotates. The field winding may be connected in parallel with the armature winding (that is, across the brushes), in which case it is known as a *shunt-field* winding. It may also be connected in series with the armature winding, in which case it is known as a *series-field* winding. The magnetic field of a generator or a motor is produced by a field winding of the shunt or series type, or by a combination of the two. Various methods may be used in winding the field poles of a generator or motor to suit the purpose for which it is to be used. Figure 185 shows the shunt winding generally used for automotive generators.

128. Shunt-Wound Generator

Most motor vehicle generators are shunt-wound with an outside means of regulating the voltage output. About 8 to 12 percent of the total current generated by the armature is shunted through the field coils for producing the magnetic field. Figure 185 represents a shunt-wound generator with only one armature coil. The armature is actually wound of many coils distributed at equal inter-

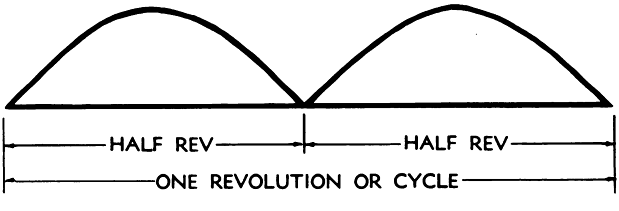


Figure 183. Current wave from single-loop direct-current generator.

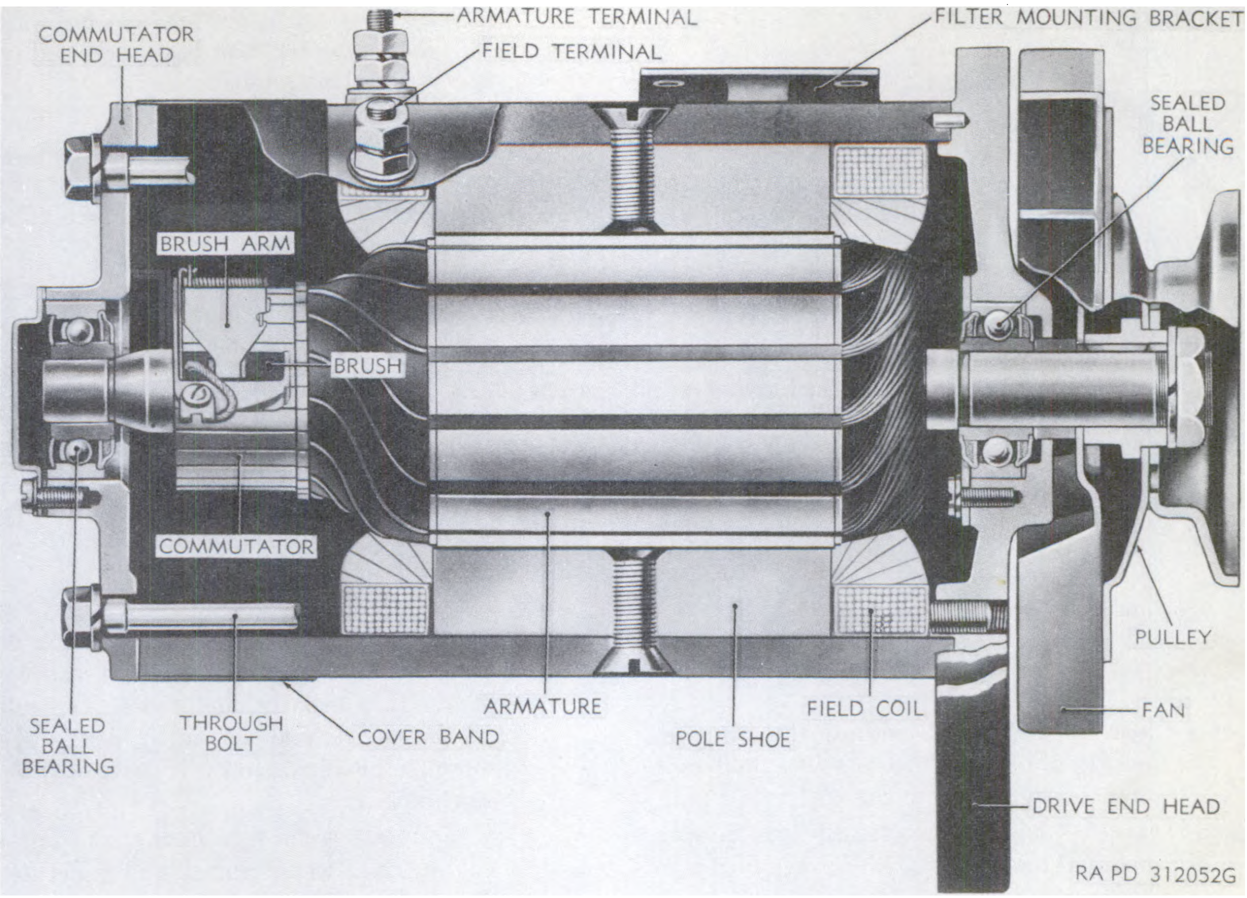

COMMUTATOR END HEAD
ARMATURE TERMINAL
FIELD TERMINAL
FILTER MOUNTING BRACKET
SEALED BALL BEARING
BRUSH ARM
BRUSH
COMMUTATOR
PULLEY
FAN
SEALED BALL BEARING
THROUGH BOLT
COVER BAND
ARMATURE
POLE SHOE
FIELD COIL
DRIVE END HEAD
RA PD 312052G

Figure 184. Generator—sectional view.

vals around it, the end of each coil being connected to a segment of the commutator in the same manner as the one shown.

a. Principle of Operation. In figure 185, assume that the magnetic field flows from the north pole piece N to the south pole piece S, as indicated by the arrows. When the armature is rotated, the armature coils will cut the weak magnetic field (residual magnetism) retained by the poles and set up a slight voltage, usually 1 to 1½ volts, across the brushes, making in this particular case the upper brush positive (+) and the lower brush negative (−). This voltage is sufficient to cause a small current to flow from the negative brush through the field winding around the pole pieces to the positive brush. If the magnetic effect of this field current is of the same polarity as the residual magnetism, the pole strength will be increased. This, in turn, will increase the magnetic field through the armature. Since the armature coils will then be cutting more magnetic lines of force per revolution, the voltage across the brushes will be increased. An increase in brush voltage increases the field strength which, in turn, increases the armature output. The armature voltage helps the field and the field helps the armature voltage until the generator reaches its normal operating voltage at the specific running speed. This process is called "*building up*" the generator voltage.

b. Residual Magnetism.

(1) In the description of generator operation (*a* above) the importance of the magnetism retained by the poles should be noted, as it serves as a foundation for building up the generator voltage.

(2) Residual magnetism is the name given to the magnetism remaining in the pole pieces and field frame after the field magnetizing current has died out. The direction of the residual magnetism may be tested by holding a pocket compass near the poles when no current is passing through the field windings or the arm-

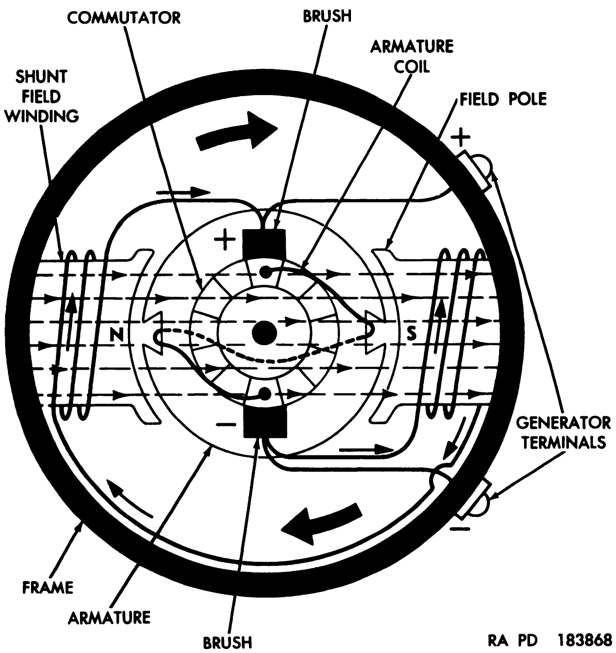


Figure 185. Diagram of a shunt-wound generator.

ature. The north end of the compass needle will point to the south field pole and the south end to the north field pole.

(3) If the field frame should lack proper residual magnetism (which may be due to its being a new or rebuilt unit, to connecting the field winding with alternating-current supply, to excessive temperature, or to vibration), the generator may be given residual magnetism by simply sending direct current through the shunt-field winding in the proper direction from either a storage battery or dry cells. This residual magnetism may be reversed by merely reversing the direction of the magnetizing field current. It may also be reversed by the magnetizing effect of the armature coils when a heavy direct current from a battery is sent through the generator armature with the field winding disconnected or open-circuited.

(4) Several conditions are necessary for the generator to build up a voltage. Two of the most important requirements are that the field frame have residual magnetism as a foundation on which to build, and that the current in each field coil be in such direction around the pole that it will produce magnetism to assist, and not oppose, the residual magnetism. If the field current opposes it, the voltage built up will not be higher than that produced by the residual magnetism.

c. Construction.

(1) The armature core is made of sheets of iron insulated from each other so that the magnetic field will not induce eddy currents in the core.

(2) The armature core is wound with coils of copper wire and mounted on a shaft with a commutator on one end (fig. 185). Field coils are made of many coils of fine wire arranged for shunt connection. The field frame, usually two or four poles with brushes, brush holders, and end housings with bearings, completes the essential parts of the generator.

d. Generator Drives.

(1) The method of mounting and driving the generator depends to a large extent on the construction and design of the engine. It is usually mounted on the side of the engine and driven by belt, silent chain, or gears at 1 to 1½ times the crankshaft speed.

(2) The present trend is to have the radiator cooling fan, water pump, and generator driven by a V-type drive belt (fig. 186) from the pulley on the forward end of the crankshaft. Pivoting the generator on the generator mounting studs permits adjustment of the belt tension. A rotary fan is usually contained on the generator pulley to draw cooling air through the generator.

(3) The generator and starter can be combined into one unit known as a *motor generator* or a *starter generator*. However, the use of one unit for the starting and generating systems is in operation on a limited scale only. More efficient operation is obtained in modern vehicles by having generator and starter as two independent machines. The generator is driven continuously by the engine, while the starter is normally disconnected from the engine and operates only when the starter switch is closed. The general arrangement of a starter and a generator is shown in figure 186.

(4) The single-wire method of wiring is used in preference to the 2-wire method by

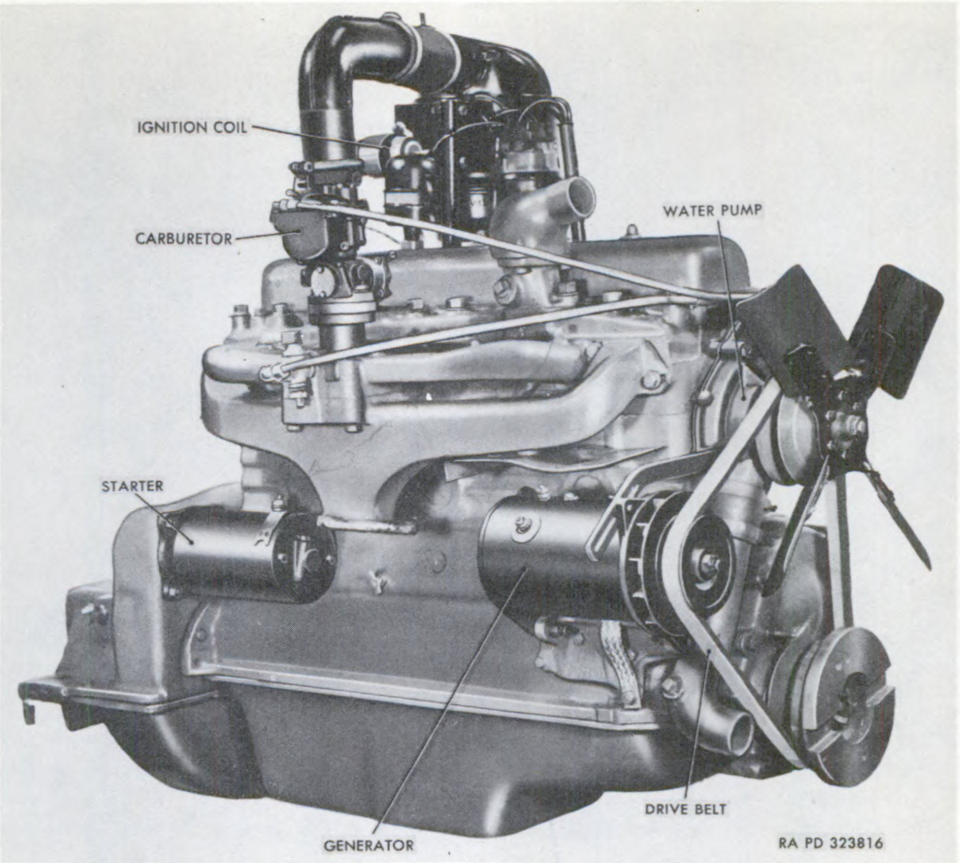


Figure 186. Typical arrangement of a starter and generator on engine.

practically all motor vehicle manufacturers, since the use of the frame in place of one wire greatly simplifies both the wiring of the vehicle and, in many cases, the construction of the starting and generating apparatus.

129. Waterproofed Generators

On many military vehicles that might be expected to ford bodies of water and to be subjected to complete immersion in water, the generators, as well as other electrical components, are made watertight. This is done by completely sealing the generator so that water cannot enter. In addition, stainless steel bearings are used to prevent corrosion. The commutator end bearing is packed with heat-resisting grease on assembly, while the drive-end bearing is lubricated by a pickup gear rotating in an oil reservoir. Neither bearing requires attention or lubrication between generator overhauls. Other types of sealed bearings may also be used. The generator leads are carried in a waterproof conduit that is connected by plug-ins to the generator terminals. The conduit (fig. 187) is attached to the generator terminal assembly by a waterproof coupling.

130. Reverse Current or Circuit Breaker

a. General.

(1) The reverse current, or circuit breaker is simply an automatic electromagnetic switch connected in the battery charging circuit between the generator and the storage battery of the electrical system. Its function is to connect the generator automatically to the battery when the voltage of the generator is sufficient to charge the battery, and to disconnect them when the generator is not running or when its voltage falls below that of the battery, to prevent the battery from discharging through the generator windings. In these respects, the action of the circuit breaker is very similar to that of a check valve between a pump and a reservoir.

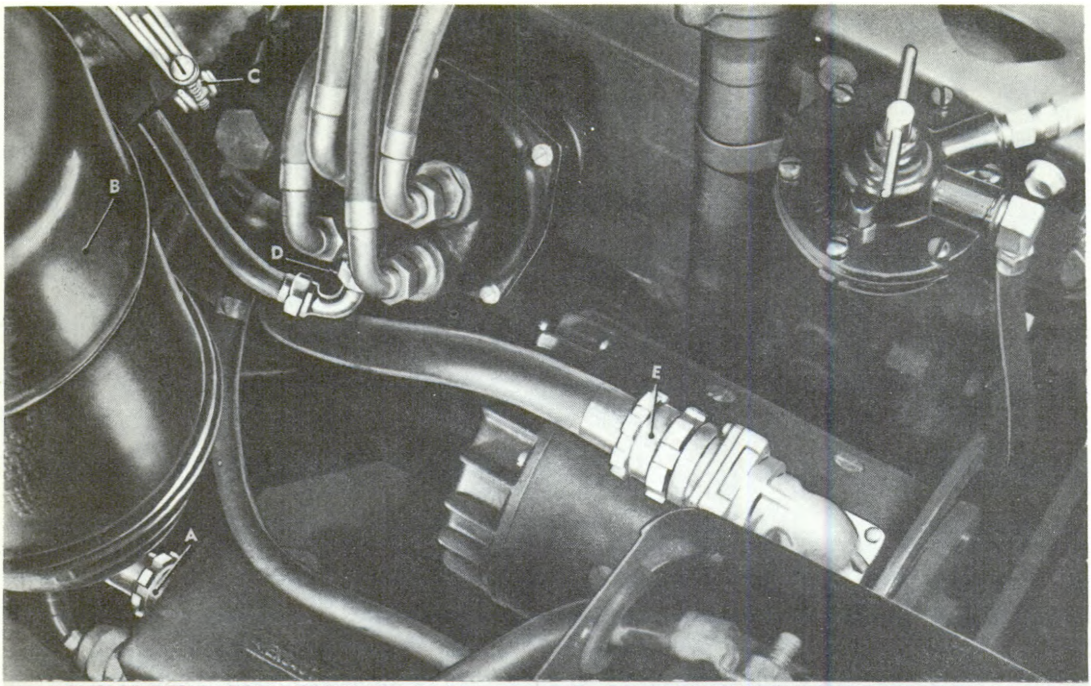

A
B
C
D
E
A—VOLTAGE REGULATOR DISCONNECT POINT
B—AIR CLEANER
C—AIR CLEANER HOSE CLAMP DISCONNECT POINT
D—PRIMARY IGNITION CABLE DISCONNECT POINT
E—GENERATOR CABLE DISCONNECT POINT
RA PD 357994

Figure 187. Generator and ignition cables in conduit, showing disconnect points for unit removal.

(2) The circuit breaker (fig. 188) consists of two windings, a shunt winding and a series winding assembled on a single core, above which is placed an armature. The shunt winding consists of many turns of fine wire, and is connected across the generator. The series winding consists of a few turns of heavy wire designed to carry full generator output, and is connected into the charging circuit. The armature carries a point which is positioned above a stationary matching point. When the generator is not operating, the armature is held away from the winding core by spring tension, and the points are separated. As soon as the generator begins to operate at a speed sufficient to produce enough voltage to charge the battery, this voltage, which is impressed on the relay windings, creates enough magnetism to overcome the armature spring tension and close the points. As long as the generator charges the battery, the points are held closed. When the generator slows or stops, so that current flows from the battery to the generator, the points open. They open because the series-winding magnetic field reverses as the current in it reverses, so that the two windings no longer help each other. The magnetic fields buck, causing a reduction of the total magnetic field to a

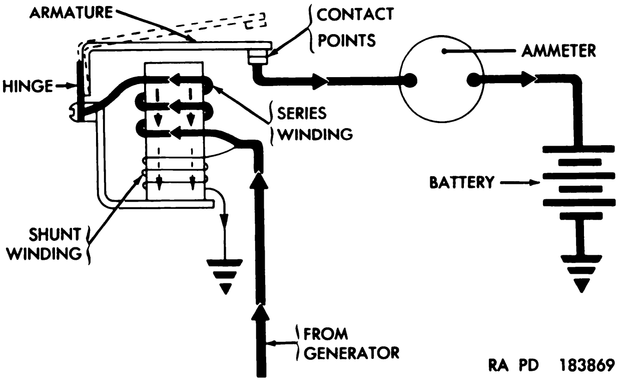

ARMATURE
CONTACT POINTS
AMMETER
HINGE
SERIES WINDING
BATTERY
SHUNT WINDING
FROM GENERATOR
RA PD 183869

Figure 188. Schematic wiring circuit of circuit breaker.

point where it can no longer hold the armature down and the points closed. The spring tension pulls the armature up and opens the points.

(3) The air gap between the armature and the iron core of the relay has little or no effect upon the voltage at which the circuit breaker opens, since the spring tension governs this almost entirely. On the other hand, the voltage at which the circuit breaker closes is governed by both the air gap and the spring tension.

131. Regulation of the Generator

a. Importance. For their magnetization, the fields of the generator depend upon the current derived from the armature of the generator. Since the current developed by the generator increases in direct proportion to its speed, the fields become stronger as the speed increases and correspondingly more current is generated by the armature. The extreme variations in speed of the automotive engine make it necessary to regulate the output of the generator to prevent excessive current or voltage overload. On the average motor vehicle, a charging current in excess of 12 to 15 amps may be harmful to a fully charged battery if continued too long. With the increased use of electrical accessories, generators have been increased in output until they are capable of producing far more than 15 amps. Some heavy-duty generators, for example, may produce as much as 150 amps. Regulation today is therefore more vital than ever before.

b. Reverse-Series Field.

(1) Since the output of the generator depends on the number of conductors in the armature, their speed of rotation, and the strength of the magnetic field in which they rotate, varying the strength of this field is the only convenient method of regulation. One of the simplest methods, used on special applications, is the use of a reverse-series field (fig. 189) for differential action. A shunt field is connected across the brushes to produce the magnetizing action. Charging current going through the reverse-series field, however, has a demagnetizing action so that, as the current increases, it tends to restrict the rise of current above a reasonable value.

(2) Such a differentially wound generator has disadvantages which limit its use on motor vehicles without some additional external regulator. If a break should occur in the charging circuit (excepting normal circuit breaker operation), destroying generator regulation by the series field, the voltage will become excessive, usually resulting in damage to the field and armature winding and to the voltage winding of the circuit breaker. Therefore, such generators usually have some form of external voltage regulation (par. 136).

c. Methods. At the present time, there are two popular methods of externally regulating the output of a generator. These are the *vibrating regulator* method and the *third-brush* method. A number of other forms have been used in the past, but most of them are now obsolete.

132. Vibrating Regulators

a. Current Regulation.

(1) The vibrating regulator can be used to regulate the current or the voltage, depending on how the regulator coil is connected. A circuit diagram of a typical vibrating regulator used for limiting the current from the generator is shown in figure 190. The regulator consists of a soft iron core, a heavy winding or current coil around the core, a set of regulator contact points normally held closed

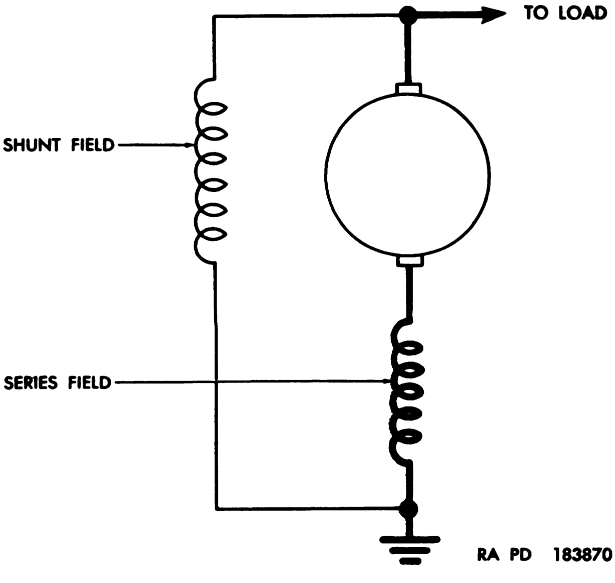


Figure 189. Schematic wiring circuit of a differentially-wound generator.

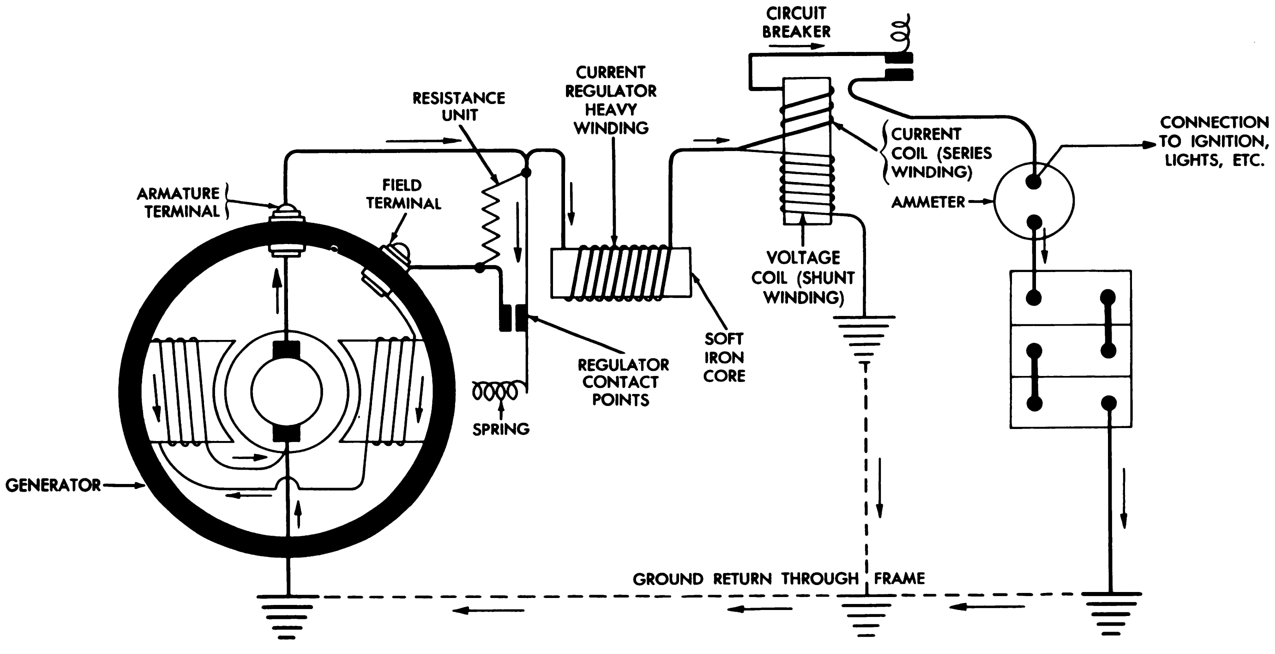

CIRCUIT BREAKER
CURRENT REGULATOR HEAVY WINDING
RESISTANCE UNIT
CONNECTION TO IGNITION, LIGHTS, ETC.
CURRENT COIL (SERIES WINDING)
ARMATURE TERMINAL
FIELD TERMINAL
AMMETER
VOLTAGE COIL (SHUNT WINDING)
SOFT IRON CORE
REGULATOR CONTACT POINTS
SPRING
GENERATOR
GROUND RETURN THROUGH FRAME
RA PD 368819

Figure 190. Vibrating current regulator—circuit diagram.

by spring tension, and a resistance unit connected across the two regulator contact points.

(2) As the generator output increases, the current regulator prevents the current output of the generator from exceeding its rated maximum by cutting a resistance intermittently in and out of the shunt-field circuit as the regulator contact points open and close, due to the varying magnetic pull of the core. The resistance is connected in the shunt-field circuit, but is normally short-circuited by the regulator contacts when they are closed. One of these is mounted on a soft iron contact armature, to which is attached the spring for holding the points in contact. The generator, when driven by the engine, builds up as a simple shunt-wound generator. When the speed and voltage of the generator are increased sufficiently to close the circuit breaker, the generator will begin to charge the battery, the charging current flowing through the regulator winding. This current flowing through the regulator winding will magnetize the core. It, in turn, exerts a magnetic pull on the regulator contact armature, which tends to separate the contacts. When the battery-charging current reaches the value for which the regulator is adjusted, the core is sufficiently magnetized to attract the armature, overcoming the pull of the regulator spring. This separates the contact points and inserts the resistance unit in series with the shunt-field winding and weakens the field strength. This causes a drop in voltage generated in the armature and, consequently, the charging current decreases. When the current decreases to a predetermined amount, the current coil does not magnetize the core sufficiently to overcome the pull of the spring, which then closes the contacts. With the contacts closed, the resistance unit is once more short-circuited and the full field strength is restored, causing the charging current to increase again. The regulator will continue to repeat this cycle. Under operating conditions, the armature vibrates rapidly enough to keep the generator output constant. As a result, the generator will never produce more than the predetermined rate (for example, 40 amps), no matter how high the speed of the car. This will be true regardless of the connected electrical load.

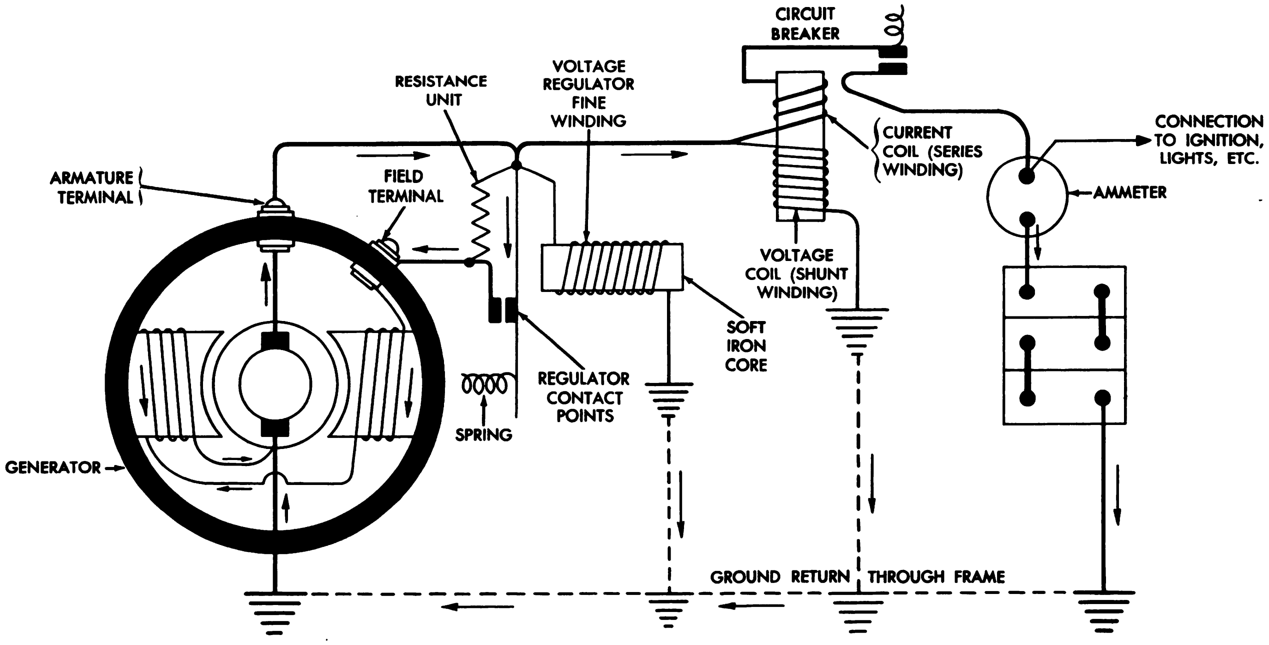

CIRCUIT BREAKER
VOLTAGE REGULATOR FINE WINDING
RESISTANCE UNIT
CURRENT COIL (SERIES WINDING)
CONNECTION TO IGNITION, LIGHTS, ETC.
ARMATURE TERMINAL
FIELD TERMINAL
AMMETER
VOLTAGE COIL (SHUNT WINDING)
SOFT IRON CORE
REGULATOR CONTACT POINTS
SPRING
GENERATOR
GROUND RETURN THROUGH FRAME
RA PD 368820

Figure 191. Vibrating voltage regulator—circuit diagram.

(3) This method of generator regulation is termed *current regulation*, since the current output of the generator is used for regulation. It is, therefore, very important that no breaks occur in the charging circuit after the generator reaches a voltage sufficient to operate the circuit breaker. If a break does occur, no current will flow through the current coil to operate the vibrating points and, due to lack of regulation, the generator will build up an excessive voltage at high speeds. To prevent such excessive voltage, a voltage regulator is used.

(4) The charging rate of the generator can be easily adjusted in all electrical systems controlled by a vibrating regulator. To increase the maximum charging rate, the spring tension on the vibrating armature should be increased slightly; and to decrease the maximum charging rate, the spring tension should be decreased. Care must be taken that the generator output does not exceed the value for which it was designed.

b. Voltage Regulation.

(1) A circuit diagram of a typical vibrating voltage regulator is shown in figure 191. Although the construction of this relay does not differ materially from that of the current regulator, the principle of operation is somewhat different. With this regulator, the voltage output of the generator is used for automatic regulation. By comparing figures 190 and 191, it will be seen that the principal difference in the two regulators is in the winding of the controlling coil and its connections. In the voltage regulator, the charging current does not flow through the regulator winding. The winding on the core consists of a voltage coil of fine wire, the two ends of which are connected across the generator brushes and in parallel with the battery instead of in series with it, as the type used for current regulation. The iron core, regulator points, and resistance unit, however, are practically the same; the only important exception is that the voltage regulator resistance is considerably higher than that used with the current regulator.

(2) The current flowing in the regulator coil and resultant magnetic pull of the core on the contact armature depend on the voltage developed by the generator. For an example of regulator operation, let

us assume the regulator is adjusted to operate at 7.5 volts. With increasing generator speed, the voltage tends to rise above 7.5 volts. However, if this value is exceeded by a small amount, the increased magnetic pull of the core on the contact armature, due to the current flowing in the voltage coil, will overcome the spring tension and pull the armature toward the core, opening the contacts and inserting a resistance in the generator field circuit. This added reresistance decreases the current in the field winding, and the voltage developed by the armature drops below 7.5 volts.

(3) When the voltage drops, the pull of the spring on the regulator armature overcomes the magnetic pull of the core and closes the contacts. This short-circuits the resistance unit and permits the field current to increase. The cycle of operation is repeated rapidly, preventing the generator voltage from rising above that for which the regulator is set. The regulator on most late-type military equipment will prevent the generator from building up an excessive voltage if a break occurs in the charging circuit. But this is not true on standard passenger cars and light-duty equipment. In these, if a break occurs in the voltage regulator circuit, regulation of the generator may be lost and at high speeds an excessive charging rate will result.

(4) It is obvious that increasing the tension of the regulator spring will increase the output voltage of the generator. Under no circumstances should the regulator spring tension be increased in an attempt to have the generator charge at a higher rate at lower speeds. The generator cannot begin to charge until the circuit breaker closes. The closing of the circuit breaker is independent of the action of the regulator. Increasing the tension of the regulator springs so that the generator will develop an excessive voltage, will send excessive current to the battery, overcharging it; or will cause the generator to overheat, with the possibility of burning it out.

c. Charging Rate.

(1) *Current regulator.* With the vibrating current regulator, the maximum possible charging current remains constant for any one setting of the regulator, regardless of the condition of the battery. To vary this maximum generator output, the spring tension of the regulator must be adjusted. The setting must never exceed the rated maximum of the generator.

(2) *Voltage regulator.*

(*a*) The main advantage of the voltage regulator is that the output of the generator is controlled to a great extent by the amount of charge in the battery. When the generator reaches a speed at which it develops the regulated voltage, there will be no further increase in voltage with increasing speed. The voltage will be maintained constant at all loads and at all higher speeds.

(*b*) During the time the generator is connected to the battery, the difference in voltage between the two is the voltage available for sending current into the battery. In a discharged battery, the difference in voltage between the generator and the battery will be relatively great, so that a comparatively high charging current will pass from the generator to the battery. As the charge continues, the voltage of the battery increases, so that the difference in voltage between the generator and the battery is continually diminishing. With a fully charged battery, the voltage is nearly equal to that of the generator so that the difference between the two is very slight. As this slight difference in voltage is all that is available for sending current into the battery, the charging current will be small. The charging current, therefore, is variable and depends upon the charge in the battery. In practice, the charging current with the constant voltage regulator varies from a maximum of 25 to 35 amps for a discharged battery to a minimum of 4 to 6 amps for a fully charged battery.

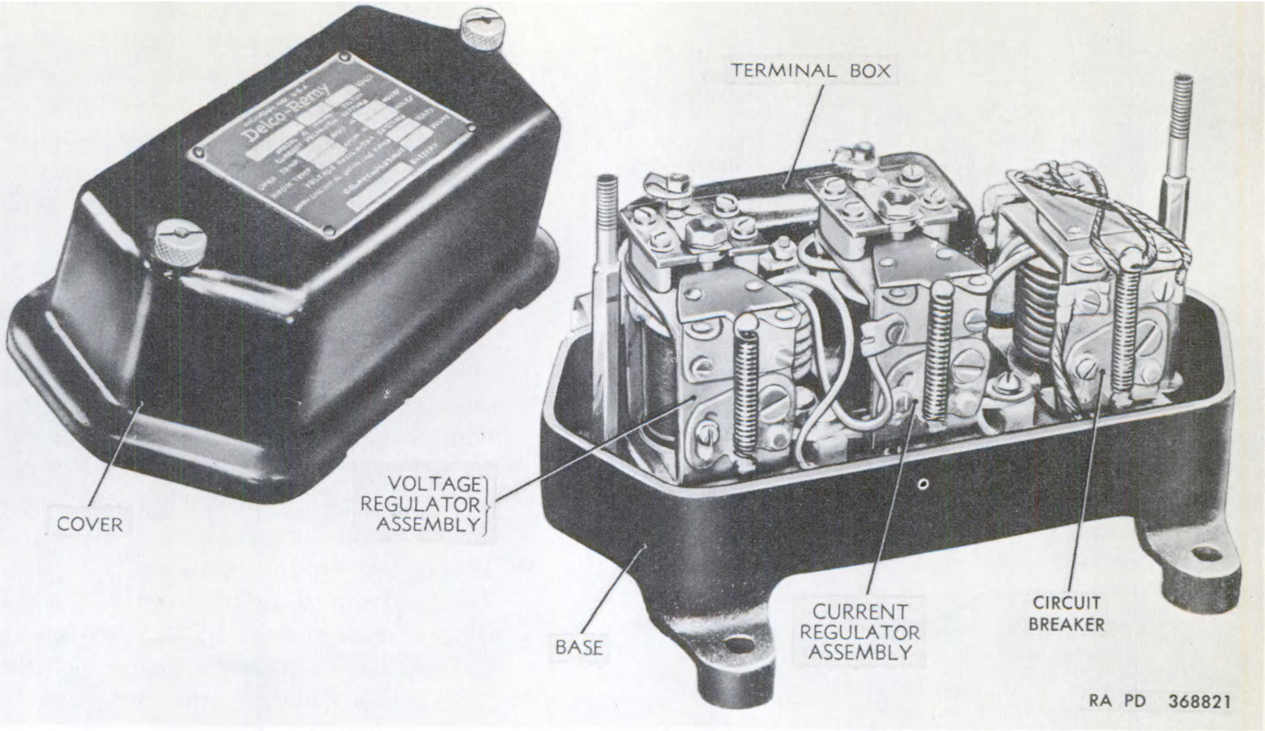


Figure 192. Current and voltage regulator.

133. Current and Voltage Regulator

a. Regulation of voltage only might be satisfactory from the standpoint of the battery, but if the battery were badly discharged, or if a heavy electrical load were connected, the generator might overload itself to supply the heavy current demand. Therefore, a current control is usually needed in addition to a voltage control.

b. In a modern current and voltage regulator, two separate regulating units are used, one to limit current and the other to limit voltage. Such a regulator consists of three elements mounted on one base with a common cover (fig. 192). The circuit breaker, current regulator, and voltage regulator each contains a separate core, coil, and set of contacts.

c. The voltage regulator in the unit shown in figure 192 is used as shown in figure 193. It is constructed and functions as follows:

(1) The windings and core are assembled into a frame. A flat steel armature is attached to the frame by a flexible hinge so that it is just above the end of the core. The armature contains a contact point which is just beneath a stationary contact point. When the voltage regulator is not operating spring tension holds the armature away from the core so that the armature contact point and stationary contact point are touching. The stationary contact point is assembled into a flat spring which rises slightly above the fiber mounting bracket when the contact points are together. This arrangement permits a wiping action between the contact points as they close and open, which assures better contact between them.

(2) When the generator voltage reaches the value for which the voltage regulator is adjusted, the magnetic field produced by the shunt winding and the reverse winding overcomes the armature spring tension, pulls the armature toward the core, and separates the contact points. This inserts a resistance into the generator field circuit so that the generator field current and voltage are reduced. However, because heavy-duty generators have highly inductive field circuits, the generator field current and voltage would normally tend to drop off rather slowly. An inductive circuit has a tendency to attempt to keep the same amount of cur-

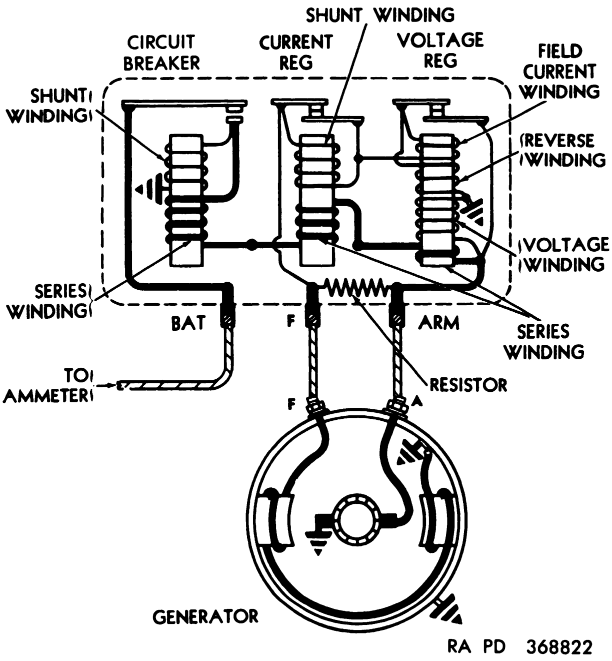


Figure 193. Wiring circuit for current and voltage regulator.

rent flowing, and opposes any change of current. But the reverse winding, which becomes connected in series with the generator field circuit as soon as the voltage regulator points open, causes a more rapid reduction of the generator voltage since it tends to reduce more quickly the current flowing in the generator field circuit. The instant before the points open, current is flowing in one direction in the reverse winding. When the points open, its connection to the generator field circuit places the reverse winding and field circuit in opposition. Since the generator field circuit has the higher inductance, it actually produces a momentary reversal of current in the reverse winding. In doing this, the generator field is appreciably reduced so that generator voltage drops off very quickly.

(3) Reversing the current flow in the reverse winding reverses its magnetic field so that it bucks, instead of aids, the shunt winding. This, in combination with the reduction of magnetic strength that the shunt winding suffers due to the lowered generator voltage, quickly reduces the magnetic attraction to a value insufficient to hold the armature down. It is released and the contact points close again. This action takes place very rapidly, holding the generator voltage to a constant value. By thus maintaining a constant voltage, the generator supplies varying amounts of current to meet the varying states of battery charge and electrical loads.

(4) The field current winding produces a magnetic field in the opposite direction to the reverse winding and shunt winding with the points closed. However, when the points open so the magnetic field of the reverse winding is reversed, the field current winding helps the reverse winding in producing quick reclosing of the contact points.

(5) The series winding provides an additional safeguard against overload, since all generator output passes through it and produces a magnetic field which influences the voltage regulator action to prevent excessive overload.

d. The current regulator (figs. 192 and 193) is constructed and functions as follows:

(1) The current regulator has two windings assembled on a single core—a series winding and a shunt winding. The core is assembled into a frame. A flat steel armature is attached to the frame by a flexible hinge so that it is held in position just above the core. The armature has a contact point which is just below a stationary contact point. When the current regulator is not operating, the tension of a spring holds the armature away from the core so that the armature contact point and the stationary contact point are touching. The stationary contact point is assembled into a flat spring which rises slightly above the fiber mounting bracket when the contact points are together. This arrangement permits a wiping action between the contact points when they open and close, which assures better contact between them.

(2) When the load demands are heavy (as, for example, when many electrical devices are turned on and the battery is in a discharged condition), the voltage may not increase to a value sufficient to cause the voltage regulator to operate. As a

result, generator output will continue to increase until the generator output reaches rated maximum. This is the current value for which the current regulator is set; thus, when the generator reaches rated output, the current regulator begins to operate to prevent the generator from exceeding its rated maximum. The current regulator operates because the magnetism produced by the current flow through the current regulator series winding is sufficient to overcome the armature spring tension so that the armature is pulled toward the winding core and the points are opened. This injects resistance into the generator field circuit, which cuts down the amount of field current, and the generator output begins to drop off.

(3) The resistance which is inserted into the generator field when the points open consists of the resistance unit and the current-regulator shunt winding. They become connected, in parallel, into the field circuit when the current regulator contact points open. This resistance causes a reduction of generator output, so that the magnetic field of the current regulator series winding is weakened, the armature released, and the points closed. This shorts out the resistance, so field current and generator output increase. The opening and closing of the contacts continues very rapidly as long as the current regulator operates, and thus the generator is prevented from exceeding its rated maximum current output.

(4) The shunt winding speeds up the contact point action. When the regulator points open, the winding becomes energized and builds up magnetically in a direction opposite to the series winding. This provides a more rapid collapse of the magnetic field so the armature is more quickly released and the points closed. This reduces fluctuation of the output to a minimum, with the result that the regulator holds the output to a more nearly constant value.

e. Just as generators are waterproofed on many military vehicles, so must the regulators be waterproofed. This consists essentially in using a seal under the cover which makes the unit watertight, and also in using a waterproof conduit (fig. 187) to carry the regulator leads.

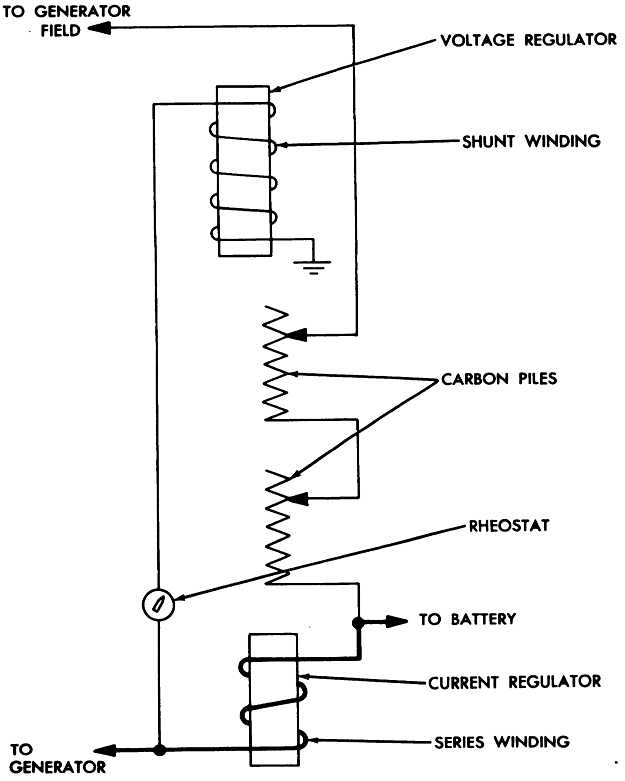
134. Carbon-Pile Regulators

a. In the vibrating-contact type regulator, a set of contacts open and close to insert and remove a resistance into and from the generator field circuit. This, in effect, inserts a variable resistance into the field circuit which controls the generator. When only a small output is required, the voltage regulator maintains the resistance in the field circuit most of the time. When output requirements increase, the resistance is in the field a smaller part of the time. This same variable-resistance effect can be achieved by a carbon-pile regulator.

b. The carbon-pile regulator consists essentially of a stack of carbon disks held together by spring pressure. The spring pressure is applied by an armature. With full spring pressure applied, the resistance through the carbon pile is relatively small. But with less pressure, the resistance increases. The carbon pile is connected into the generator field circuit so that its resistance is in series with the field. With full pressure applied, there is no regulation and generator output can increase to a high value. To limit current output to a safe value, or to provide voltage regulation, the armature pressure can be varied to vary the resistance.

c. To limit current, or to provide current regulation, the carbon-pile regulator has a heavy winding through which all current from the generator must pass (fig. 194). This winding produces a magnetic pull as current passes through it, which opposes the armature spring pressure. When the output reaches the value for which the generator is rated, the magnetic pull overcomes the spring pressure sufficiently to reduce the pressure on the carbon disks and thereby increase the resistance of the pile. This increased resistance, which is in the generator field circuit, prevents any further increase of output.

d. To regulate voltage, a shunt winding is incorporated in the carbon-pile voltage regulator. This shunt winding is connected across the generator so that generator voltage is imposed on it. When this voltage reaches the value for which the regulator is set, the winding produces enough magnetic pull on the armature to reduce the armature spring pressure. This causes the resistance of the voltage-regulator carbon pile to increase. The increased resistance, which is in the generator field



RA PD 183873

Figure 194. Wiring diagram of a carbon-pile current and voltage regulator—it has two carbon piles and two windings.

circuit, prevents any further generator voltage increase and thereby reduces generator output.

e. The rheostat (fig. 194) is connected into the shunt-winding circuit of the voltage regulator. Its purpose is to permit adjustment of the voltage regulator setting. When all resistance in the rheostat is cut out (by turning the knob), the full generator voltage is imposed in the shunt winding. But when some of the rheostat resistance is cut in, less than full generator voltage is imposed on the shunt winding (part of it being in the rheostat). In the latter case, generator voltage must go higher before voltage regulation commences. Thus, accurate setting of the regulator can be made.

135. Paralleling Generators

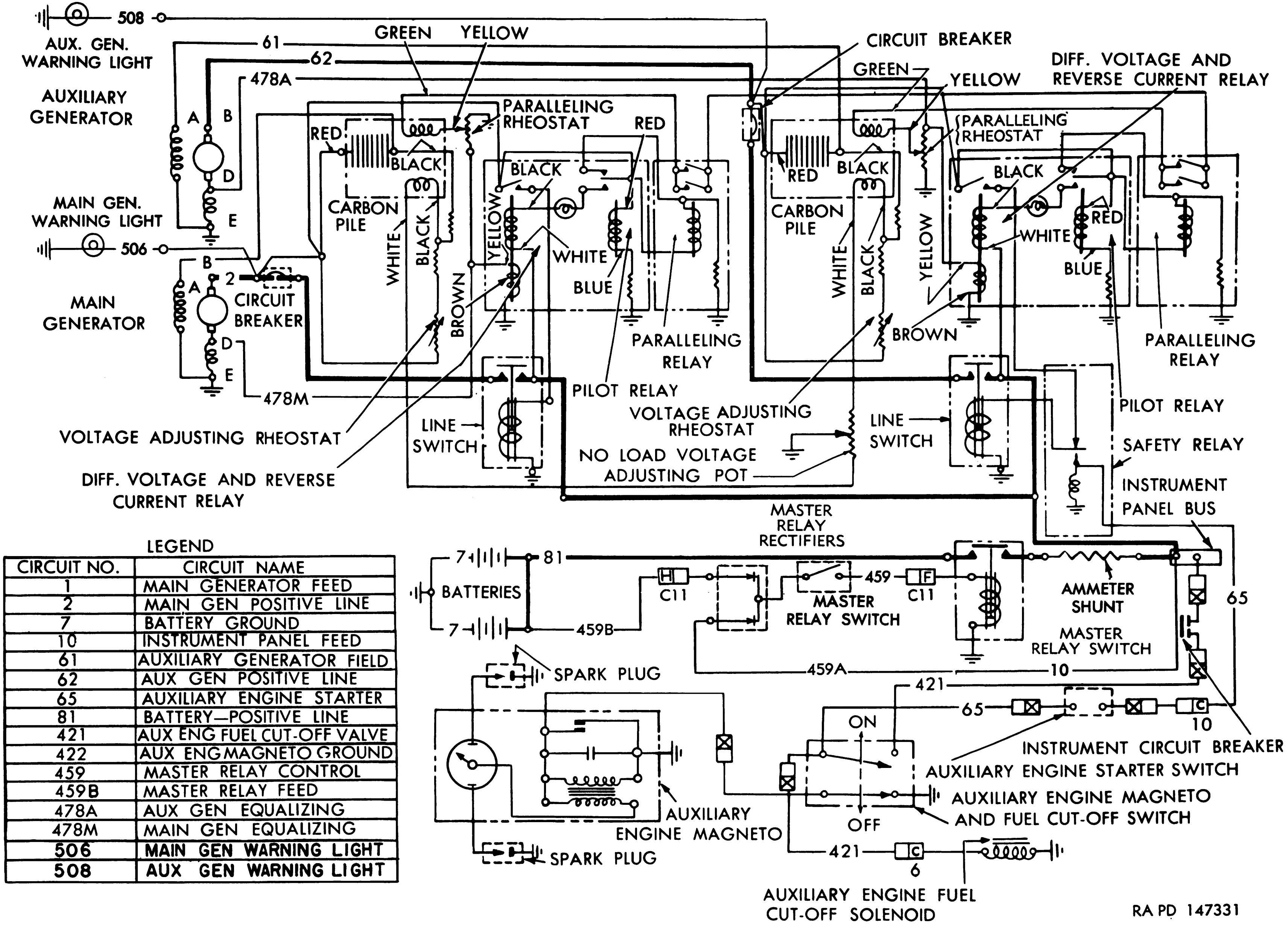
a. Some military vehicles have two separate power plants, each with its own generator and regulator working into a common set of batteries. Certain combat vehicles have a single power plant, but they also carry an auxiliary generator. In any case, where two generators are working into a single set of batteries and a single electrical system, the problem of paralleling exists. That is, the two generators must be connected in parallel. Unless special provision is made, trouble may result if two generators are paralleled. The reason for this is that one generator may attempt to carry most or all of the load while the other generator might even do the reverse of produce output, it might use current or act like a motor. The problem is further complicated if one of the generators varies in speed (as the unit on the power plant might).

b. To provide effective paralleling, each of the voltage regulators contains an additional paralleling winding. These windings become connected to each other through two paralleling relays when both generators are operating. With this condition, the paralleling windings can increase the voltage (and thus the output) of the lagging generator and, at the same time, decrease the voltage (and thus the output) of the generator which is producing more than its share. By this means, the two generators can be kept in step. An actual installation is explained in paragraph 136.

136. Generator System—Main and Auxiliary Generators

a. General. An actual wiring circuit, in schematic form, of a combat vehicle using a main and auxiliary generator is shown in figure 195. This system uses two generators, two carbon-pile regulators, plus various relays and switches. Figure 196 shows the junction box, with cover removed, which contains the regulators and relays.

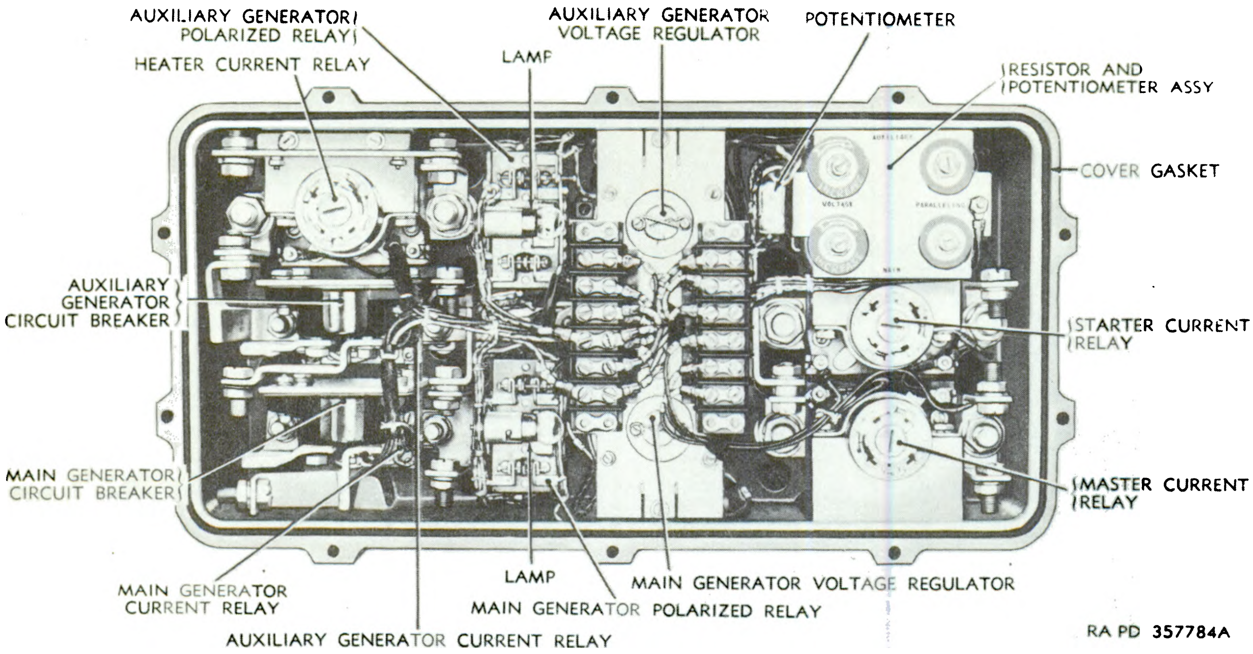
b. Generator. The generator is essentially a shunt generator with a maximum output of 150 amps, and is used with a 24-volt battery set. The generator contains an additional field winding of a few turns of very heavy wire through which the entire generator output passes. This is a series winding. It is so wound that its magnetic field opposes the magnetic field from the shunt windings. This acts as a current-limiting device since the higher the output, the greater the opposition from the series-winding magnetic field. When the output reaches the rated maximum, the series-winding field is so strong that it effectively prevents any further increase in output. Further increases would further strengthen the series-winding field, thus further bucking the shunt-winding field and causing a decreased total field and, consequently, a dropping off of output. This series-field


508
AUX. GEN. WARNING LIGHT
61
62
478A
GREEN
YELLOW
AUXILIARY GENERATOR
A
B
D
E
MAIN GEN. WARNING LIGHT
506
2
CIRCUIT BREAKER
MAIN GENERATOR
478M
PARALLELING RHEOSTAT
RED
BLACK
CARBON PILE
WHITE
YELLOW
BROWN
PARALLELING RELAY
PILOT RELAY
VOLTAGE ADJUSTING RHEOSTAT
NO LOAD VOLTAGE ADJUSTING POT
LINE SWITCH
DIFF. VOLTAGE AND REVERSE CURRENT RELAY
BLUE
SAFETY RELAY
INSTRUMENT PANEL BUS
MASTER RELAY RECTIFIERS
81
7
BATTERIES
459B
H
C11
459
F
MASTER RELAY SWITCH
AMMETER SHUNT
65
459A
10
421
SPARK PLUG
AUXILIARY ENGINE MAGNETO
ON
OFF
INSTRUMENT CIRCUIT BREAKER
AUXILIARY ENGINE STARTER SWITCH
AUXILIARY ENGINE MAGNETO AND FUEL CUT-OFF SWITCH
C
6
AUXILIARY ENGINE FUEL CUT-OFF SOLENOID
RA PD 147331

LEGEND

CIRCUIT NO.	CIRCUIT NAME
1	MAIN GENERATOR FEED
2	MAIN GEN POSITIVE LINE
7	BATTERY GROUND
10	INSTRUMENT PANEL FEED
61	AUXILIARY GENERATOR FIELD
62	AUX GEN POSITIVE LINE
65	AUXILIARY ENGINE STARTER
81	BATTERY—POSITIVE LINE
421	AUX ENG FUEL CUT-OFF VALVE
422	AUX ENG MAGNETO GROUND
459	MASTER RELAY CONTROL
459B	MASTER RELAY FEED
478A	AUX GEN EQUALIZING
478M	MAIN GEN EQUALIZING
506	**MAIN GEN WARNING LIGHT**
508	**AUX GEN WARNING LIGHT**

Figure 195. Generator system—schematic diagram.


AUXILIARY GENERATOR POLARIZED RELAY
HEATER CURRENT RELAY
LAMP
AUXILIARY GENERATOR VOLTAGE REGULATOR
POTENTIOMETER
RESISTOR AND POTENTIOMETER ASSY
COVER GASKET
AUXILIARY GENERATOR CIRCUIT BREAKER
STARTER CURRENT RELAY
MAIN GENERATOR CIRCUIT BREAKER
MASTER CURRENT RELAY
MAIN GENERATOR CURRENT RELAY
LAMP
MAIN GENERATOR VOLTAGE REGULATOR
MAIN GENERATOR POLARIZED RELAY
AUXILIARY GENERATOR CURRENT RELAY

RA PD 357784A

Figure 196. Master junction box—cover removed.

winding in the generator also plays an important part in the operation of the regulators and certain relays in the control system (*c* and *d*, below).

c. Pilot Relay. There is a pilot relay for each generator. Since both operate the same, the one used with the main generator will be discussed (fig. 195). It contains a shunt winding which is connected across the main generator terminals. In addition, it has two sets of contacts, an upper set and a lower set. The upper set is used in conjunction with the paralleling system, so consider the lower set first. This lower set is open when the generator is not operating. But when the generator begins to run and its voltage increases sufficiently to charge the battery, then the lower set closes. The shunt winding in the relay produces this action since, with sufficient voltage, it has a strong enough magnetic pull to pull the relay armature down and close the lower contacts. When the lower contacts close, this causes the differential-voltage-and-reverse-current relay to operate.

d. Differential-Voltage-and-Reverse-Current Relay.

(1) *Closing.* When the pilot relay closes its points, one of the windings in the differential-voltage-and-reverse-current relay becomes connected between the insulated batterly terminal and the installed generator terminal. If the generator voltage is greater than the battery voltage, the difference (or differential) between the two causes current to flow in the winding (which is called the differential-voltage winding). As this current flows, a magnetic field is produced which pulls the relay armature down and causes relay contacts to close. When the relay contacts close, the line-switch winding is connected across the generator so that it closes, thereby directly connecting the generator to the battery.

(2) *Opening.* With the relay and line switch closed so the generator charges the battery, current flows through the battery and back to the generator by means of ground wire and the series winding in the generator field. Since the current is flowing through the series winding, there is a voltage difference between the two ends of this winding. This voltage varies with the rate of current. With a high generator output, a high current is flowing and the voltage across the series winding is greater. This voltage is applied to the differential-voltage-and-reverse-current relay. When the generator is charging and the relay is closed,

this voltage is imposed across a second winding in the relay (the reverse-current winding) in such a direction as to help the differential-voltage winding hold the relay contacts closed. But when the generator voltage falls below the battery voltage, the battery begins to discharge through the generator. In other words, the current reverses. This means that the current in the series-field winding, and thus the voltage across the series-field winding, also reverses. The resultant reverse voltage, which is applied to the reverse-current winding, causes the magnetic field of this winding to reverse. Consequently, this winding no longer helps the differential-voltage winding, but opposes it. As a result, the total magnetic field is so weakened that the relay armature is pulled up by its spring tension and the contacts open, thereby, opening the line switch winding circuit so the line switch opens. This disconnects the generator from the battery.

e. Line Switch. The line switch is a simple magnetic switch. When its winding is electrically energized, it pulls the armature down so the switch is closed. When the winding is disconnected, the spring pressure under the armature moves the armature up so the switch opens.

f. Paralleling Relays.

(1) *Connections.* In operation, the contacts of the paralleling relays are connected in series with the paralleling windings in the two voltage regulators and to the two series-field windings in the two generators. Whenever a generator begins to charge, the armature on the pilot relay moves from the upper to the lower position, thereby, opening the upper and closing the lower contacts. When the upper contacts are closed (meaning that the generator is not charging), the paralleling relay winding is shorted through them and no paralleling relay action can take place. But when the pilot relay opens these upper contacts and closes the lower contacts, the winding of the paralleling relay becomes connected across the generator. Now, generator voltage can energize the winding and cause the paralleling relay to close its contacts. If only one generator is operating only one paralleling relay will be actuated. This means that no paralleling can take place. But when both generators are operating so that both paralleling relays are in action, then the contacts of the relays, the paralleling windings in the regulators, and the series-field windings in the generator are all in series.

(2) *Operation.* When all are in series, current will flow in the circuit if one generator is putting out more current than the other. To understand how this might be, refer to figure 197, which is a simplified sketch of the generator series-field windings and the regular paralleling windings connected in series. The paralleling relay contacts are not shown here since they are closed and are therefore a part of the circuit. Suppose that the main generator is putting out more current than the auxiliary generator. This means that more current flows through the series-field winding of the main generator than through the series-field winding of the auxiliary generator. Under these conditions, there will be a greater voltage across the main generator series-field winding. This means that current will flow from this winding, through the paralleling windings, and the auxiliary generator series-field winding. The current flow through the paralleling windings in the regulators helps the regulating winding in one regulator and opposes the regulating winding in the other. It helps in the main generator regulator; this means that the spring pressure on the carbon-pile armature is further lightened so that the carbon-pile resistance increases, thereby, cutting down the main generator output. On the other hand, the paralleling winding in the auxiliary generator regulator opposes the regulating winding. This means that the spring pressure on the carbon-pile armature is increased. Carbon-pile resistance is reduced and the auxiliary generator output goes up.

(3) *Paralleling.* With paralleling, if one generator tries to produce more output than the other, its output is immediately

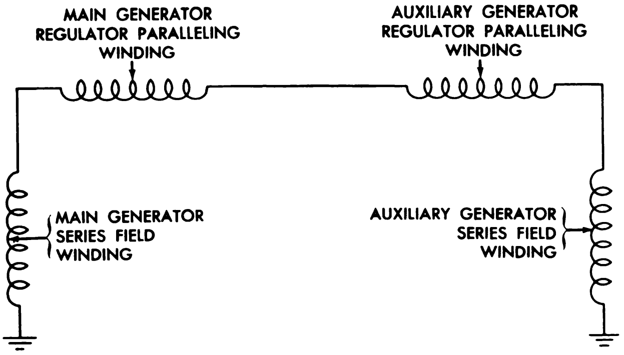

MAIN GENERATOR REGULATOR PARALLELING WINDING
AUXILIARY GENERATOR REGULATOR PARALLELING WINDING
MAIN GENERATOR SERIES FIELD WINDING
AUXILIARY GENERATOR SERIES FIELD WINDING
RA PD 183874

Figure 197. Generator series-field windings and regulator paralleling windings.

cut down while the output of the low generator is increased. The action is entirely automatic once the system has been correctly adjusted. In order to achieve adjustment, the voltages of the two carbon-pile regulators must first be set, then the voltages perfectly balanced by means of the no-load voltage-adjusting potentiometer, or "pot." Finally, the two paralleling rheostats must be adjusted. All these adjustments must be made by authorized personnel and according to instructions supplied in the applicable technical manual.

g. Regulators. The carbon-pile regulators, one for each generator, operate on generator voltage (par. 134). A simplified sketch of one carbon-pile regulator circuit is shown in figure 198 (paralleling winding not shown). Some special features of this circuit will be of interest. The carbon pile is connected between the insulated generator brush and the generator shunt field. Essentially, the regulator winding is connected across the generator brushes so that full generator voltage is imposed on it. It therefore regulates on generator voltage as explained in paragraph 134. There is a voltage adjusting rheostat connected in series with the winding so that voltage adjustment can be made (par. 134 *e*). In addition, the circuit goes to ground through a potentiometer. This potentiometer permits accurate balancing of the two voltage regulator settings. For instance, if one regulator is slightly higher than the other, but both are within specifications, balance can be achieved by turning the potentiometer knob slightly. This puts more resistance into one regulating winding circuit and takes it out of the other, and thus achieves the desired results.

137. Third-Brush Regulation

Third-brush regulation is much simpler in operation and less expensive to manufacture than other methods of control. However, it can be used only for relatively small and specialized applications. Generators with this type of control have an extra brush called the *third brush*, located between the two main brushes.

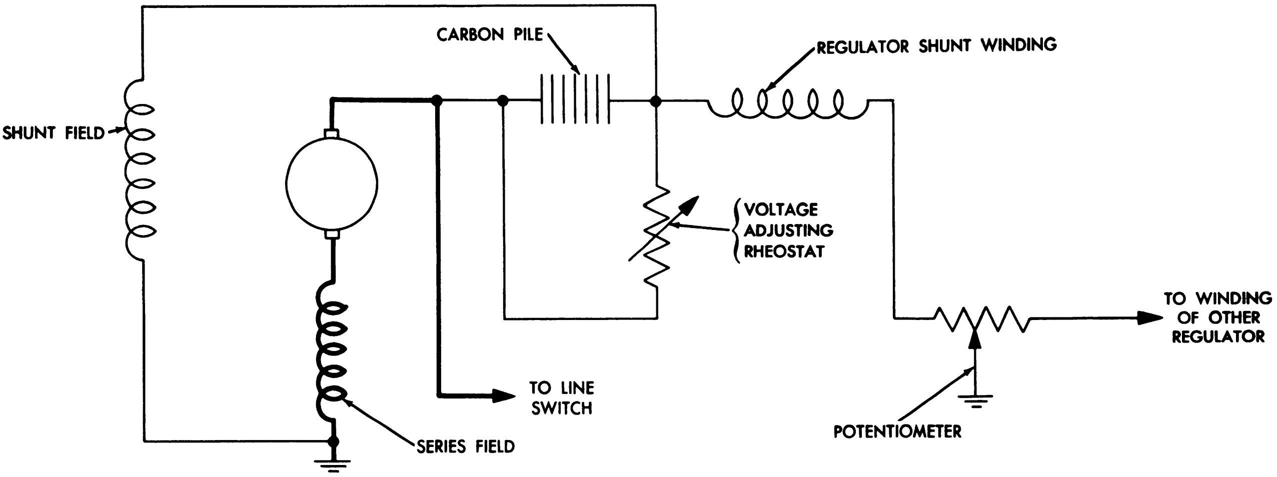
a. Arrangement. Arrangement of a typical 2-pole, third-brush generator is shown in figure 199. One end of the shunt-field winding is connected to the third brush, the other end is grounded. Only a part of the total voltage generated is supplied to the field by the third brush.

b. Operation.

(1) When the generator is running at a low speed and little or no current is flowing in the armature winding, the magnetic field produced by the field windings is approximately straight through the armature from one pole piece to the other (fig. 199(1)). The voltage generated by each armature coil is then practically uniform during the time the coil is under the pole pieces.

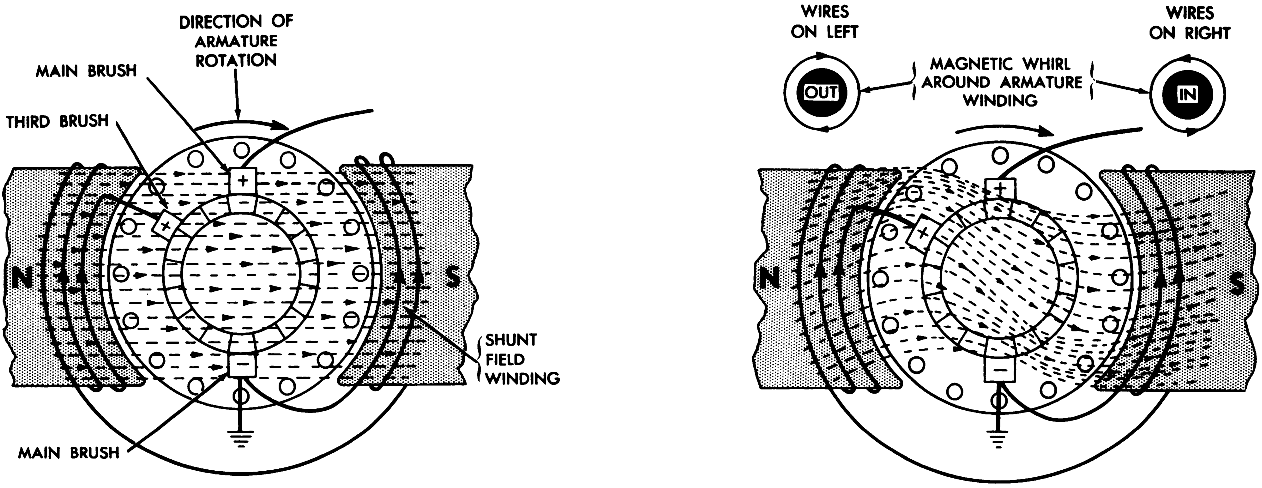
(2) As the generator speed and current increase, the armature winding acts like a solenoid coil to produce a cross magnetic field. The magnetic whirl around the armature winding distorts the magnetic field produced by the shunt-field windings so that the magnetism is not equally distributed under the pole pieces (fig. 199(2)). With this distortion of the magnetic field, the armature coils no longer generate a uniform voltage while passing under the different parts of the pole. Although the voltage across the main brushes remains nearly the same, a greater proportion of this voltage is generated by the coils between the positive brush and the third brush than was generated between them when little current was flowing through the armature winding. This is due to the distortion of the magnetic field, which crowds more magnetic lines of force between the positive and the third brush.

(3) The coils which connect the commutator between the negative and the third brush


CARBON PILE
REGULATOR SHUNT WINDING
SHUNT FIELD
VOLTAGE ADJUSTING RHEOSTAT
TO WINDING OF OTHER REGULATOR
TO LINE SWITCH
SERIES FIELD
POTENTIOMETER

RA PD 183875

Figure 198. Carbon-pile regulator circuit.


DIRECTION OF ARMATURE ROTATION
MAIN BRUSH
THIRD BRUSH
N
S
+
-
SHUNT FIELD WINDING
MAIN BRUSH
WIRES ON LEFT
WIRES ON RIGHT
MAGNETIC WHIRL AROUND ARMATURE WINDING
OUT
IN

(1) LITTLE OR NO CURRENT FLOWING (LOW SPEED).

(2) LARGE CURRENT FLOWING (HIGH SPEED).

RA PD 183876

Figure 199. Third-brush generator regulation.

are in the region of the weakened field and generate a lower proportion of the voltage. The result is a dropping off of the voltage between the negative and third brushes, which is applied to the shunt-field winding, thereby weakening the field strength. As the field strength decreases with increased generator current, the result will be an automatic regulation of the current output.

c. Output.

(1) One of the outstanding characteristics of generators with third-brush regulation is that the output of the generator increases gradually up to an intermediate speed. After this, due to pronounced field distortion, the output falls off as the speed continues to increase. At high generator speeds, the output is approximately one-half its maximum value.

(2) In practically all generators which have third-brush regulation, provision is made for changing the output to suit the conditions under which the generator is operated. This can be done by moving the position of the third brush on the commutator. It is evident that the average voltage applied to the field winding will

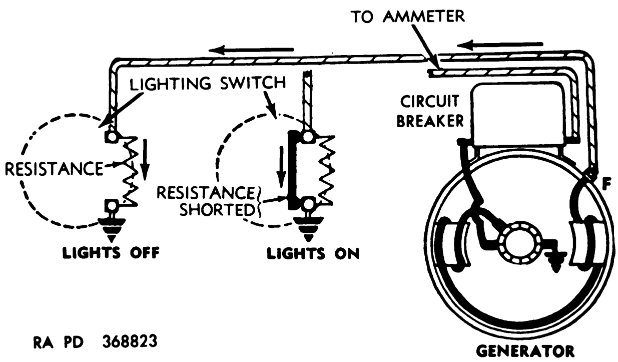


Figure 200. Lighting switch control of third-brush generator.

depend upon the number of armature coils spanned by the brushes which collect the field current. Thus, moving the third brush in the direction of the armature rotation increases the average current delivered to the shunt-field winding and, consequently, the output of the generator. Moving the brush against the direction of armature rotation decreases the output. Whenever this brush is moved, care should be taken to see that it makes perfect contact with the commutator.

(3) Since the third-brush generator depends upon the current flowing through the armature winding to produce the field distortion necessary for regulation, it is obvious that it is current regulated internally (as distinct from external current regulation). It must therefore have a complete circuit available through the battery at all times, otherwise regulation would be destroyed and excessive field currents would burn out the generator windings. Should the third-brush generator be disconnected from the battery for any reason, the generator terminals must be grounded.

138. Control of Third-Brush Generator

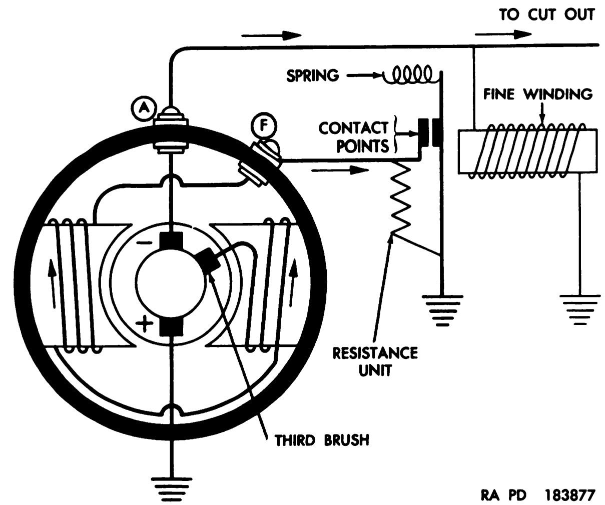
To guard against the possibility of the third-brush generator burning up, a fuse is sometimes provided in the field circuit. When used, it is placed either in the generator end plate or in the regulator control unit. If the battery becomes disconnected, there is a rise in voltage at the generator. This, in turn, sends an abnormally heavy current through the field winding and this field current burns out the fuse. As soon as the fuse is blown, the field circuit is open and no current can flow through it. The generator then merely turns, producing practically no voltage, and does no harm. The third-brush generator provides current regulation only and does not take battery voltage into consideration. In fact, a fully charged battery which has a high voltage will actually get more current from a third-brush generator than a battery which is completely discharged, because the high voltage holds up the voltage at the generator, makes the field stronger, and causes the generator output to increase. This, combined with the varying demands of radio sets and other current-consuming devices, necessitates more accurate regulation than a third-brush generator alone can give.

a. Switch Control. Practically all systems of regulation provide a means for inserting a resistance in series with the third-brush field. A simple way of accomplishing this is shown in figure 200. A resistance is mounted on the back of the lighting switch and connected in series with the field. When the lights are off, the generator output current is limited by the resistance in the field circuit. When the lights are turned on, the resistance is shorted so that the generator delivers full current to take care of the additional lighting circuit load. This is just a two-step arbitrary system of regulation, however, which will not meet the varied load requirements of normal vehicle operation.

b. Step-Voltage Control.

(1) The purpose of step-voltage control is to increase or decrease the output of a third-brush generator in accordance with the requirements of the battery and the connected electrical load. It is really a two-stage regulator in which the change from one output to the other is controlled by the generator voltage which, in turn, is controlled by battery voltage.

(2) A step-voltage control unit is shown in figure 201. A fine-winding voltage coil, connected to the generator armature terminal (A, fig. 201) so that it receives the armature voltage, is the controlling element. Contacts are connected in series with field terminal (F, fig. 201) and have a resistance unit connected across them.


TO CUT OUT
SPRING
FINE WINDING
A
F
CONTACT POINTS
-
+
RESISTANCE UNIT
THIRD BRUSH

RA PD 183877

Figure 201. Step-voltage control of third-brush generator.

When the battery is fully charged, or nearly so, its voltage raises the generator voltage to such a value that sufficient magnetizing current flows through the fine winding on the control unit to pull the contact points apart. When this happens, the resistance across the contacts is connected in series with the field winding to lower the field strength and, consequently, to reduce the generator voltage and the current output. When the voltage is lowered sufficiently, spring tension will close the contact points and the higher charging rate will be restored.

(3) When there is sufficient electrical load (such as lights, radio, heater, etc.) to require a higher generator output, the contact points will close, since the load will lower the generator voltage and the generator will produce its maximum output for the selected position of the third brush and the speed at which it is driven.

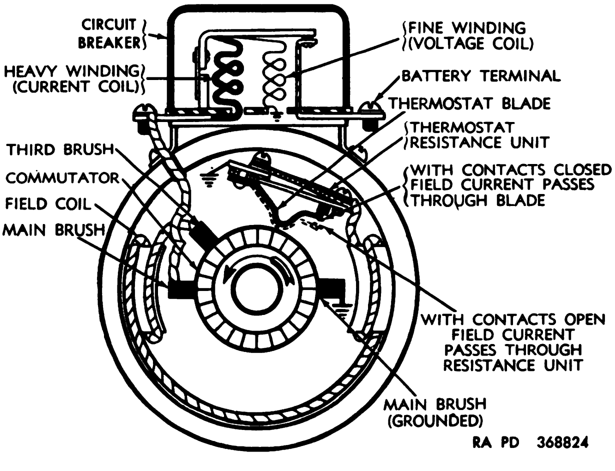
c. Vibrating Regulator Control. A vibrating regulator can also be used with a third-brush generator. Such a regulator is controlled by a voltage coil which operates vibrating contacts. When the battery is discharged, there is insufficient voltage to operate the regulator. The generator output is then controlled only by the third brush. As the battery becomes charged, the voltage of the system will increase and more current will be forced through the regulator coil. The regulator points then begin to vibrate, connecting a resistance in the generator field circuit and cutting down the output to a fairly constant value. This system is discussed in paragraph 132*b*.

d. Thermostatic Control.

(1) Another type of control for the third-brush generator uses a thermostat blade to control the field strength. If the generator is set to give the greatest possible current to take care of demands during the winter, in warm weather the battery would be in a constant state of overcharge and soon be ruined. The thermostat blade automatically takes care of the changing current demands under different conditions.

(2) It consists of a bimetal thermostat blade made of a strip of spring brass welded to a strip of nickel steel. The blade warps or bends when heated, due to the greater expansion of the brass side. The blade is set so that a contact on its end is held firmly against a stationary contact at low temperatures. When the temperature rises to approximately 160° to 165° F., the blade bends and separates the contacts.

(3) The thermostat is connected in the third-brush field circuit (fig. 202) so that the full field current passes through the thermostat contacts when closed, permitting full current from the generator. After the engine has been run long enough for the high charging rate to heat the generator, the thermostat contacts


CIRCUIT BREAKER
HEAVY WINDING (CURRENT COIL)
THIRD BRUSH
COMMUTATOR
FIELD COIL
MAIN BRUSH
FINE WINDING (VOLTAGE COIL)
BATTERY TERMINAL
THERMOSTAT BLADE
THERMOSTAT RESISTANCE UNIT
WITH CONTACTS CLOSED FIELD CURRENT PASSES THROUGH BLADE
WITH CONTACTS OPEN FIELD CURRENT PASSES THROUGH RESISTANCE UNIT
MAIN BRUSH (GROUNDED)

RA PD 368824

Figure 202. Thermostatic control of third-brush generator.

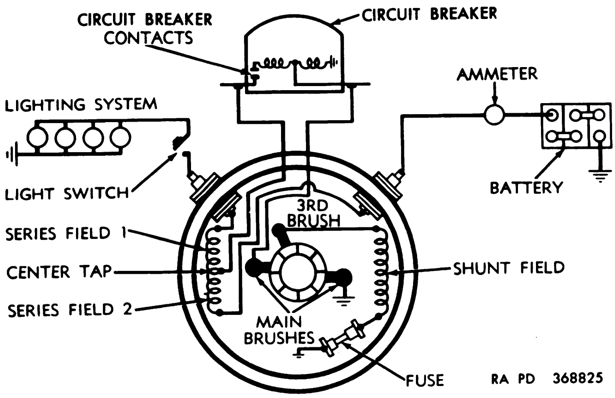


Figure 203. Split-series-field generator.

open (due to the bending of the thermostat blade), causing a resistance unit across the contacts to be connected in series with the third-brush field and thereby reducing the current output. The charging rate is reduced approximately 30 percent when the thermostat contacts are opened.

(4) The chief advantages of thermostatic control are that it gives a large battery-charging rate in cold weather when the efficiency of the battery is lower than in warm weather, and also a larger charging rate when the vehicle is being driven intermittently and the demands on the battery are greater because of frequent use of the starter. This control also prevents the generator and the battery from overheating in summer, by reducing the charging rate when the temperature rises.

139. Split-Series-Field Generators

a. Generator regulation is sometimes accomplished by means of a split-series field. A generator with this method of regulation combines third-brush, reversed-series (differential), and cumulative compound principles. The series-field winding is divided so that the generator output is changed according to the load.

b. With lights off, no current flows through one part of the series field (1, fig. 203). The current going to the battery flows through the remainder of the series field (2, fig. 203) in the opposite direction to the shunt-field current. This weakens the total field strength, keeping the generator output down for the delivery of a reasonable charging rate.

c. When the lighting switch is closed, the entire lighting current flows through section 1 of the series field in the same direction as the shunt field. The strength of the field is thereby increased, giving a higher generator output to take care of the lighting load.

d. If the lights are turned on before the generator circuit breaker closes, the entire lighting current is supplied by the battery. This current then flows through all of the series field, instead of through section 1 only, in the same direction as the shunt field, making the total field strength still greater. This will build up the generator voltage to close the circuit breaker. The entire current output of the generator, which passes through the circuit breaker flows to the center tap of the series field where it divides, part of the current flowing in one direction through to the battery and the remainder to the lights.

e. As soon as the circuit breaker closes, the generator begins to pick up the lighting load. This lessens the drain on the battery and thereby reduces the current flowing through section 2 of the series field. When the generator output just equals the lighting current, the current in section 2 is zero and, as the generator output increases further, current begins to flow in the reverse direction through section 2 to the battery. This tends to weaken the field built up by the shunt winding and section 1 of the series winding. By obtaining the proper relationship between the shunt winding and the two sections of the series winding, results quite similar to those obtained from voltage regulation are secured, and the battery is kept in a charged condition.

f. The charging rate of the split-series-field generator may be adjusted by shifting the third brush as in the regular third-brush generator. In some generators of this type, separate coils are used for the two sections of the series field. In others, the two sections are combined into one coil. Generators of this type do not have standard connections and must not be confused with the ordinary third-brush generator. Neither terminal should be grounded under any circumstances. Proper connections are shown in figure 203.

g. See paragraph 364*b* for a description of a lamp-load regulated third-brush generator, such as is used on some motorcycles.

Section IV. STARTING SYSTEM

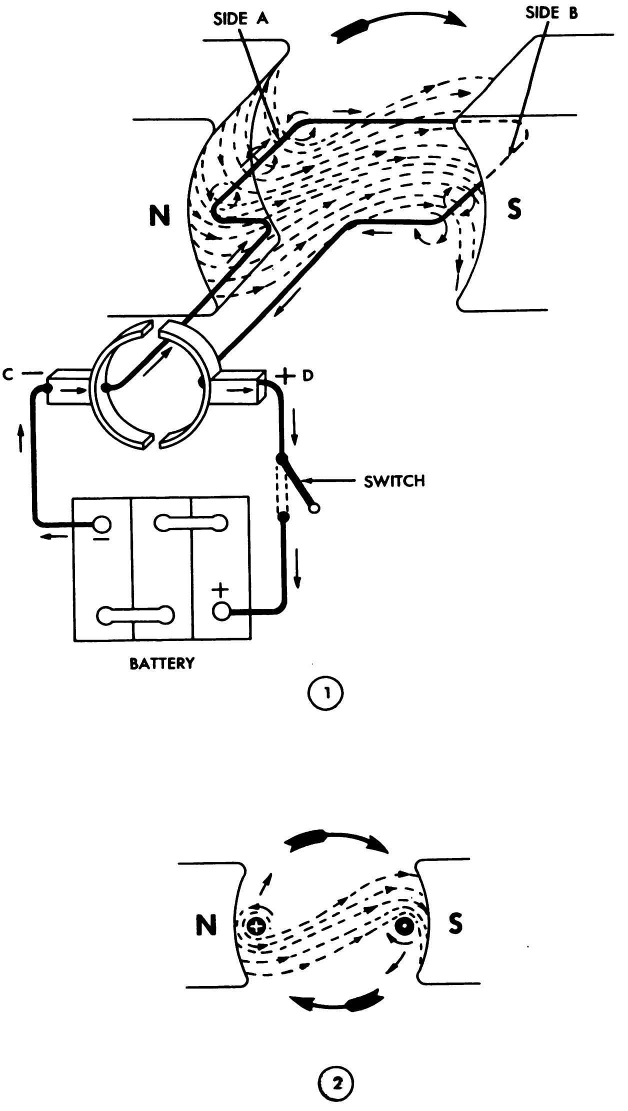


Figure 204. Simple single-loop direct-current motor.

140. Electric Starter

The electric starter, having supplanted the mechanical and air starters, is now furnished as standard equipment on all passenger cars, most trucks, and on some tractor, airplane, and marine engines. The electric starter is a low-voltage direct-current motor capable of developing high torque, and is supplied with current from the battery.

141. Simple Direct-Current Motor

a. Fundamentally, an electric motor is constructed the same as a generator. If the brushes of the simple generator are connected to a battery and current is permitted to flow through the loop of wire (fig. 204), the loop of wire will rotate in the direction indicated by the arrow. Briefly, this rotation is due to the repulsion between the field magnetism and the magnetic whirl set up around the loop of wire by the current.

b. The repulsion is caused by all the magnetic lines of force tending to flow around the conductor in the same direction. This distorts and crowds the magnetic lines on one side of the conductor more than on the other, which results in a repulsion of the conductor (fig. 205(1)). In other words, the rubber-band characteristic of the lines of force (par. 117), whereby they try to shorten to a minimum length, causes the lines to exert a push on the conductor. If the magnetic field is reversed, with the direction of current unchanged, the magnetic lines of force will crowd to the other side of the conductor, and it will be repelled in the opposite direction (fig. 205(2)). The same action would result if the current instead of the magnetism were reversed. Thus, in figure 204, owing to the current flowing in reverse directions in the two sides C and D of the loop, and the consequent field distortion (fig. 205(2)), C will be repulsed upward and D downward, and the loop will rotate in a clockwise direction.

c. In practice, the motor armature has many armature coils equally spaced around the entire circumference of the armature (fig. 206), each of which carries current and consequently exerts a force to rotate the armature as it passes the pole pieces. The result is a comparatively high turning power (or torque) which, if applied through suitable gear reductions, is sufficient to crank the engine.

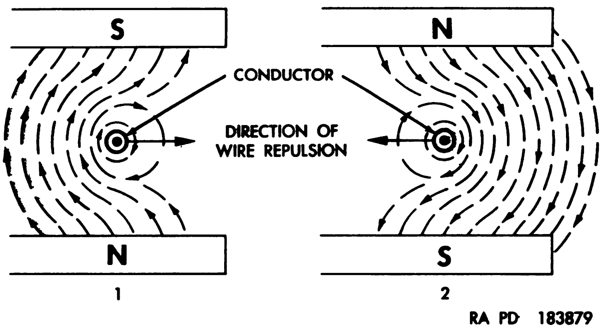


Figure 205. Wire repulsion in magnetic field (current coming out).

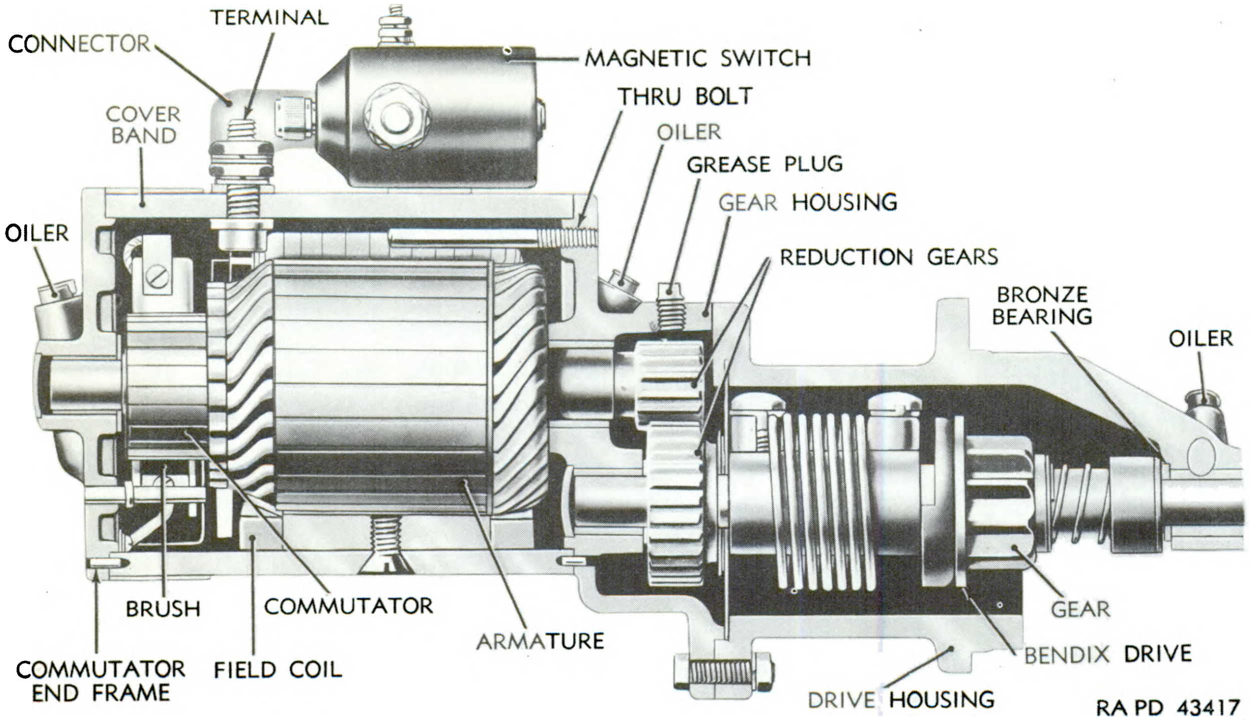


Figure 206. Starter with Bendix drive—outboard type.

142. Starter

The starter may drive the engine through a pinion or by a dog clutch attached to the starter armature shaft, which is brought into mesh with teeth cut on the rim of the flywheel or into mesh with the mating half of the dog clutch. The drive must be equipped with an overrunning clutch or some other means of quick disengagement. Owing to limitations of size and capacity of the battery, a high-speed starter with a high gear reduction is used to obtain the necessary torque. The great speed reduction required is effected in the majority of cases by utilizing the flywheel as a driven gear. In some instances, the gear is bolted or shrunk on the flywheel, while in others the gear teeth are cut directly in the rim of the flywheel itself. The starter (fig. 186) is mounted on the flywheel housing.

a. Gear Reduction. The gear reduction obtained through the flywheel gear with a single reduction is usually about 11:1 or 12:1 (sometimes it is as high as 16:1); that is the speed of the starter armature is 11 or 12 times that of the flywheel. The pinion gear on the armature shaft meshes directly with the gear teeth on the flywheel. In some instances, however, a double reduction is used (fig. 206), in which case the gear ratio may be as high as 25:1 or even 40:1. With double reduction, the gear on the armature shaft does not mesh directly with the teeth on the flywheel but with an intermediate gear which drives the flywheel driving pinion. The double-reduction drive permits the use of a very small starter running at high speed, but it has the disadvantage of requiring a more complicated mechanism than the single-reduction drive.

b. Pedal Shift.

(1) With this type of starting mechanism, the starter pinion is meshed when the driver presses the starter pedal. Such a system is shown in figure 207.

(2) When the yoke lever is moved by the action of the driver in stepping on the starter pedal, the pinion gear is shifted into mesh with the flywheel gear. After the gears are in mesh, continued movement of the pedal operates the starter switch and causes the starter to crank the engine. In case the pinion does not mesh perfectly with the flywheel, further motion of the shift lever compresses a spring so that the pinion will snap into mesh the instant the starter armature

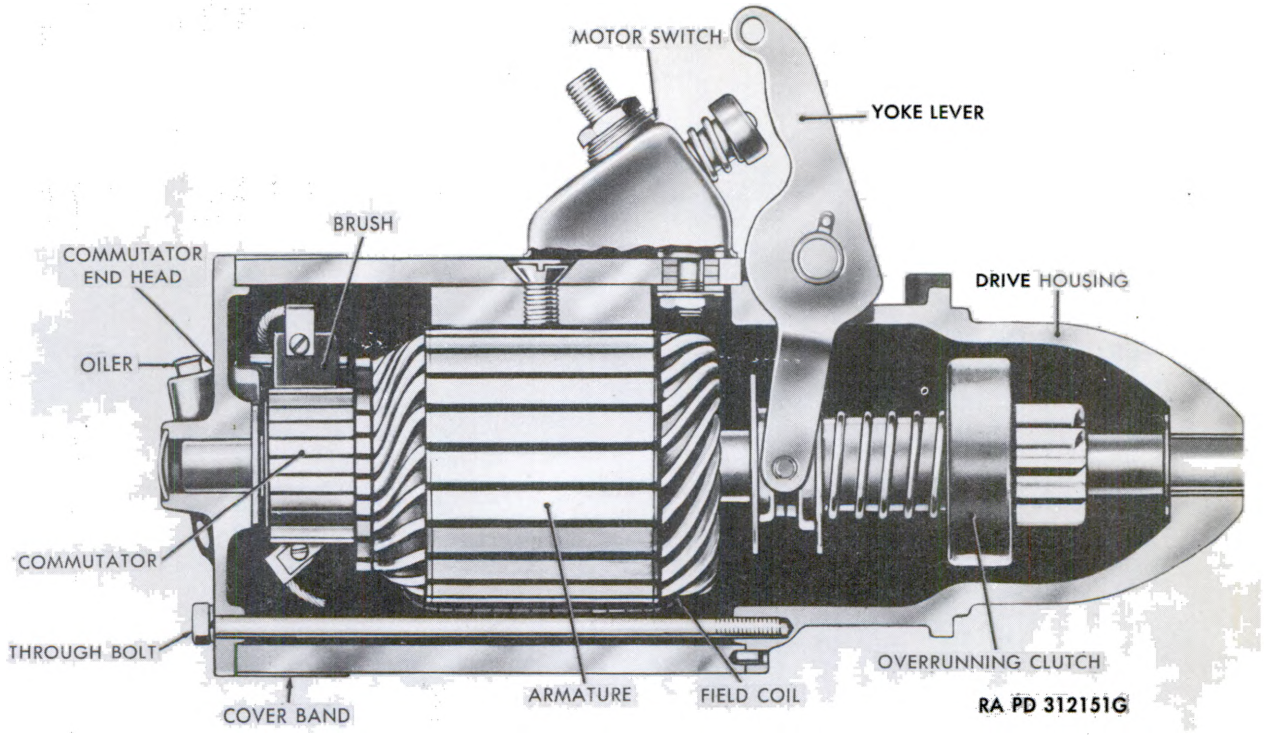


Figure 207. Starter with overrunning clutch.

begins to rotate. After the engine has started, releasing the starter pedal will pull the pinion out of the mesh.

c. Overrunning Clutch. Power can be transmitted through the overrunning clutch in one direction only, which prevents the engine from driving the starter. The shell and sleeve assembly of the clutch (fig. 208) is driven by the starter armature shaft, the inner portion, or rotor being connected to the pinion which meshes with the teeth on the engine flywheel. Steel rollers are located in wedge-shaped spaces between the rotor and the shell. Springs and plungers normally hold the rollers in position within the wedge spaces. When the starter armature shaft turns, the rollers are jammed between the wedge-shaped surfaces, causing both the inner and the outer members to rotate as a unit and crank the engine. As soon as the engine transmits power through the pinion in a reverse direction, the pinion and rotor assembly (fig. 208) is driven by the flywheel and tends to work the rollers back against the plungers to where the space is greater, thereby, causing a slipping or overrunning action. As a result, the clutch cannot be driven in this direction. This prevents excessive speeds of the starter.

d. Bendix Drive. The Bendix drive is a starting mechanism used on many cars. This automatic screw pinion shift mechanism is built in two distinct styles: the inboard type, in which the pinion shifts toward the starter to engage the flywheel, and the outboard type (fig. 206), in which the pinion shifts away from the starter. The same general construction is used in both types. A sleeve having screw threads (usually a triple thread), with stops at each end to limit the lengthwise travel of the pinion, is mounted on the extended armature shaft. The pinion gear, which is unbalanced by a weight on one side, has corresponding internal threads for mounting on this sleeve. The sleeve is connected to the starter armature shaft through a special drive spring attached to a collar pinned to the armature shaft.

(1) *Operation.* When the starter is not operating, the pinion is out of mesh and entirely away from the flywheel gear. When the starter switch, which may be foot- or hand-operated, is closed and the total available battery voltage is impressed on the starter, the armature immediately starts to rotate at high speed. The pinion, being weighted on one side and having internal screw threads, does

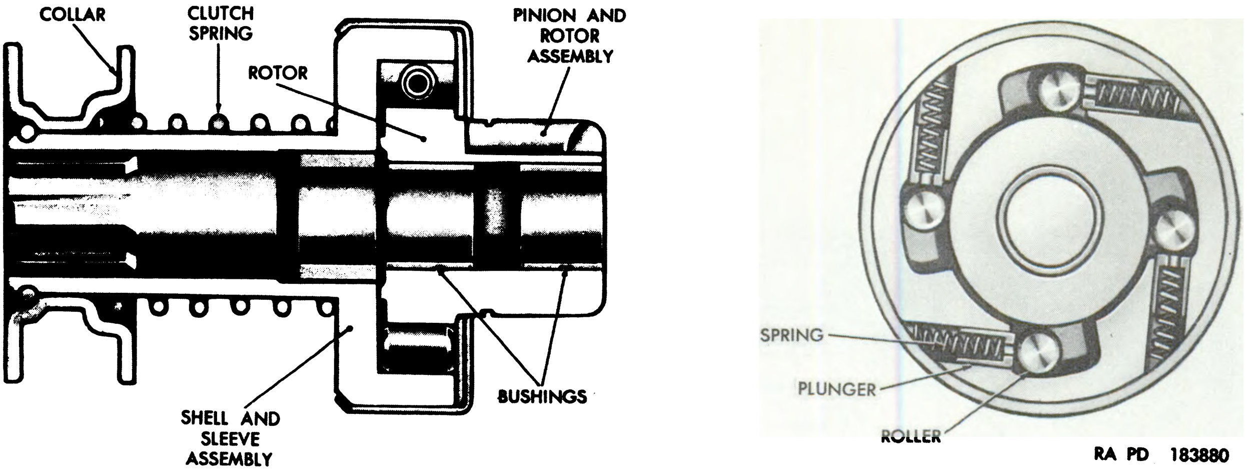


Figure 208. Typical overrunning clutch construction.

not rotate immediately with the shaft but, because of its inertia, runs forward on the revolving threaded sleeve until it meets or engages with the flywheel gear. If the teeth of the pinion and the flywheel meet instead of engaging, the drive spring allows the pinion to revolve and forces it into mesh with the flywheel. When the pinion gear is fully engaged with the flywheel gear, the pinion is then driven by the starter through the compressed drive spring and cranks the engine. The drive spring acts as a cushion while the engine is being cranked against compression. It also breaks the severity of the shock on the teeth when the gears engage and when the engine kicks back due to ignition. When the engine fires and runs on its own power, the flywheel drives the pinion at a higher speed than does the starter, causing the pinion to turn in the opposite direction on the threaded sleeve and automatically disengages from the flywheel. This prevents the engine from driving the starter. When the pinion is automatically disengaged from the flywheel, it is held in this position by a latch until the starter switch is again closed.

(2) *Advantages.* The chief advantages claimed for this type of starter are listed in (*a*) through (*d*) below.

(*a*) It is simple in construction.

(*b*) The mechanism is automatic in operation, requiring no action by the operator other than pressing the starter switch.

(*c*) It gives high starting speed, because the starter is permitted to pick up speed before the load is applied.

(*d*) The engine is given a high cranking torque immediately, thus, requiring little cranking and minimizing the demand on the battery.

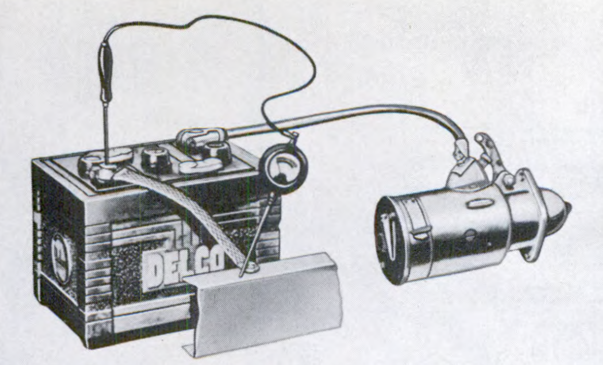
(3) *Disadvantages.* The chief disadvantages are listed in (*a*), (*b*), and (*c*) below.

(*a*) The quick impulse given to the pinion is likely to cause nicking or breaking of the teeth when the pinion does not mesh properly on first contact with the flywheel teeth.

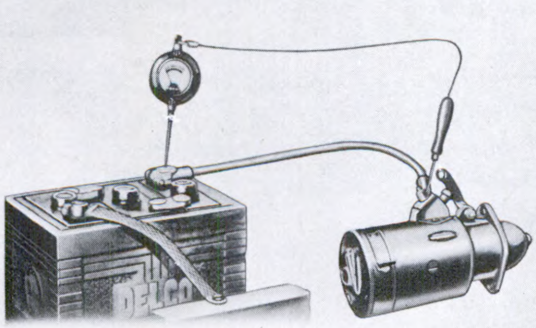
(*b*) Breakage or nonfunctioning of the pinion latch will cause the pinion to drift toward the flywheel teeth, which is likely to cause damage if the engine is running.

(*c*) All of the starter torque is transmitted through the drive spring, which puts it under considerable strain.

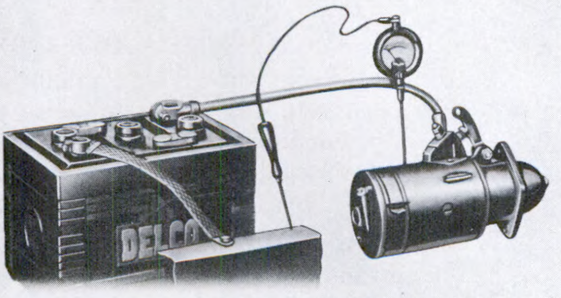
e. Starter Circuit Test. If the circuits between the battery and starter are not in good condition, poor cranking of the engine will result. Conditions that could cause poor cranking include poor terminal connections and damaged or defective cables or leads. These conditions can be detected with an accurate, low-reading voltmeter (fig. 209) and explained in (1) (2), and (3) below. The tests measure the voltage drops produced by the



VOLTAGE DROP TEST BETWEEN BATTERY GROUND TERMINAL AND FRAME



VOLTAGE DROP TEST BETWEEN UNGROUNDED BATTERY TERMINAL AND STARTER SWITCH



VOLTAGE DROP TEST BETWEEN STARTER AND FRAME

RA PD 368826

Figure 209. Using low-reading voltmeter to check voltage drops in circuits between starter and battery.

defective circuit conditions; the greater the voltage drops, the worse the defects.

(1) Check voltage drop between grounded battery terminal and vehicle frame. Place one prod of test voltmeter on grounded battery terminal and the other on vehicle frame. With ignition switch off, crank engine with starter. If voltmeter reading is more than one-tenth of a volt, there is excessive resistance in this circuit and ground strap must be cleaned or replaced.

(2) Check voltage drop between ungrounded battery terminal and starter switch stud. Place one prod of voltmeter on ungrounded battery terminal and the other on the starter switch stud. With ignition switch off, crank engine with starter. If voltmeter reading is more than one-tenth of a volt, there is excessive resistance in this circuit and terminals must be cleaned or cable replaced.

(3) Check voltage drop between starter housing and vehicle frame. Place one prod of test voltmeter on starter housing and the other on vehicle frame. With ignition switch off, crank engine with starter. If voltmeter reading is more than one-tenth of a volt, there is excessive resistance in this circuit. Remove and clean or replace transmission to frame ground strap or tighten the starter to clutch housing mountings.

143. Solenoid Shift

Shifting the overrunning clutch pinion gear into mesh with the flywheel gear is made automatic on a good proportion of modern vehicles by the use of a solenoid.

a. Definition of Solenoid. A solenoid is a coil of wire wound in the form of a helix of one or more layers, which produces a magnetic field when a current is passed through it. The magnetic field thus produced flows in concentric circles around the wire.

b. Operation of Solenoid Shift. A remote control switch is necessary to operate the solenoid. The ignition switch is connected into the control circuit so that the starter will not operate until the ignition is on. The solenoid shift unit is rigidly mounted on the starter field frame. Inside the solenoid coil is a heavy plunger connected to the shift lever (figs. 211 and 212). The two larger terminal posts on the shift unit are connected in series with the starter. The smaller terminal which leads to the solenoid is connected into the remote control circuit. When the remote control circuit is closed to supply current to the solenoid coil, the solenoid exerts a pull on the shift plunger, which shifts the pinion to engage with the flywheel teeth. After the pinion shift

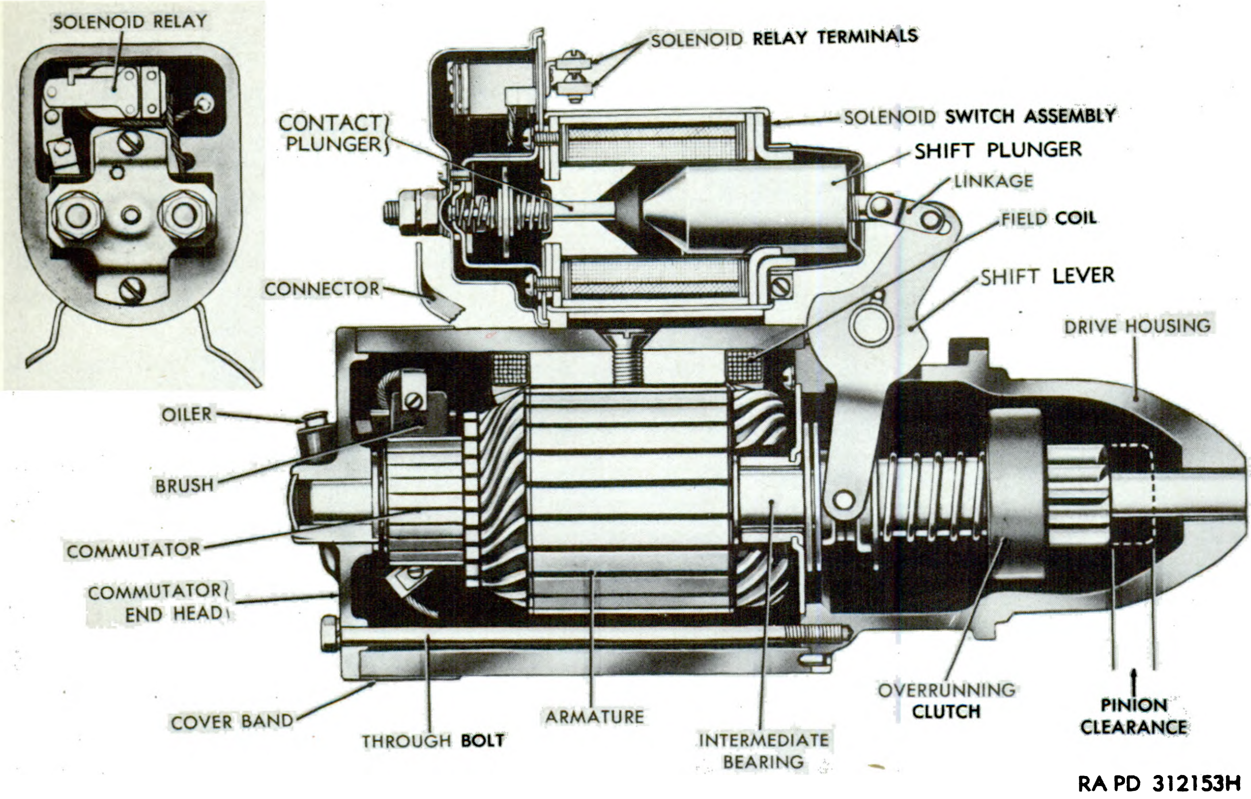

SOLENOID RELAY
SOLENOID RELAY TERMINALS
CONTACT PLUNGER
SOLENOID SWITCH ASSEMBLY
SHIFT PLUNGER
LINKAGE
FIELD COIL
CONNECTOR
SHIFT LEVER
DRIVE HOUSING
OILER
BRUSH
COMMUTATOR
COMMUTATOR END HEAD
COVER BAND
THROUGH BOLT
ARMATURE
INTERMEDIATE BEARING
OVERRUNNING CLUTCH
PINION CLEARANCE
RA PD 312153H

Figure 210. Solenoid shift starter with overrunning clutch.

lever has moved the distance required for engaging the pinion gear, the pointed end of the shift plunger presses against the end of a contact plunger and pushes a contact disk on the contact plunger across the switch contacts to operate the starter. An overrunning clutch is required with this system to prevent damage to the starter at the time the engine fires.

c. Push Button Control.

(1) One method of controlling the solenoid shift is by a push button on the instrument panel. Pushing the button closes the control circuit so that current can be supplied to the solenoid coil.

(2) A relay is frequently used in the control circuit to supply current to the solenoid coils (fig. 211). Only a low current control circuit to the instrument panel push button is then necessary. The relay will close the circuit through the solenoid coil which carries a larger current.

d. Vacuum Control.

(1) A vacuum switch, operated by movement of the accelerator in combination with a control relay, is another method of controlling the solenoid. This combination, when properly adjusted, eliminates the possibility of the starter operating while the engine is running.

(2) Vacuum switch control of the starter solenoid is shown in figure 212. When the ignition switch is on and the vacuum switch contact points are closed, current will flow through the control circuit as indicated by arrows in figure 212. The solenoid relay is then energized and its contacts closed to supply current to the solenoid shift unit which operates the starter. The control circuit is completed through generator brushes or field to the ground connection on the generator.

(3) Depressing the accelerator pedal operates a linkage which turns the throttle cam (fig. 212) counterclockwise and moves the push rod away from the contact blade. When the engine is not operating, the blade will move with the push rod to close the vacuum switch contacts.

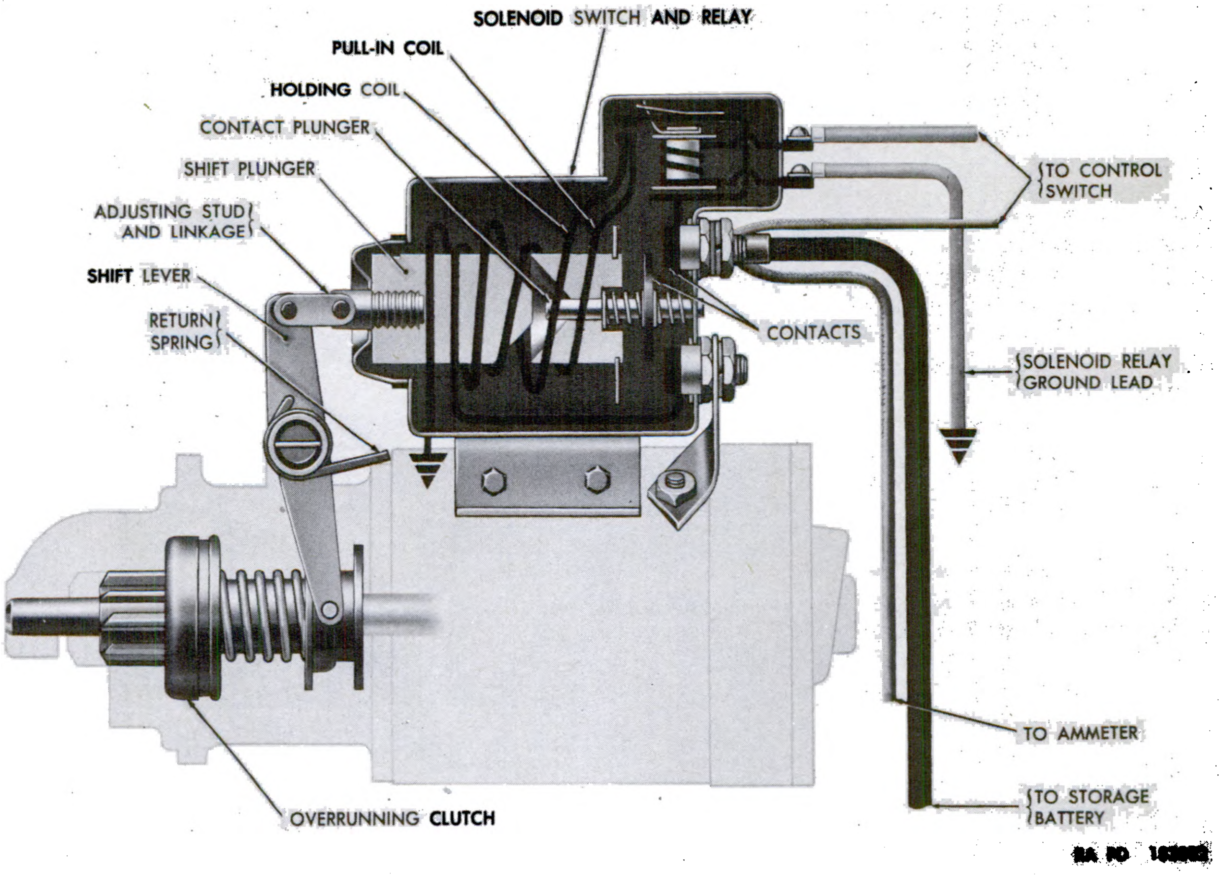

SOLENOID SWITCH AND RELAY
PULL-IN COIL
HOLDING COIL
CONTACT PLUNGER
SHIFT PLUNGER
ADJUSTING STUD AND LINKAGE
SHIFT LEVER
RETURN SPRING
TO CONTROL SWITCH
CONTACTS
SOLENOID RELAY GROUND LEAD
TO AMMETER
TO STORAGE BATTERY
OVERRUNNING CLUTCH
RA PD [illegible]

Figure 211. Wiring circuit of solenoid shift starter with overrunning clutch.

The vacuum produced in the manifold when the engine starts causes the diaphragm to compress the spring and rotate the switch cam. The lug on the switch cam opens contact points and latches on an insulated pin on the contact blade, holding the points open. When the engine stops or stalls, there is no vacuum in the intake manifold and the spring tends to push the diaphragm back to its original position, but it is held by the latched switch cam. When the foot is taken off the accelerator pedal, the push rod pushes against the contact blade sufficiently to unlatch the cam and allows the vacuum diaphragm to return to its original position. The contact points are held open by the push rod but, when the accelerator is depressed to start the engine, the push rod moves away from the contact blade and the points close to operate the starter solenoid.

(4) The solenoid relay is mounted on the solenoid shift (fig. 212). In some cases, it is mounted on top of the generator with the circuit breaker. The contact points in the solenoid relay close at 4.3 to 4.7 volts and remain closed while cranking, until the battery voltage becomes 2.0 volts

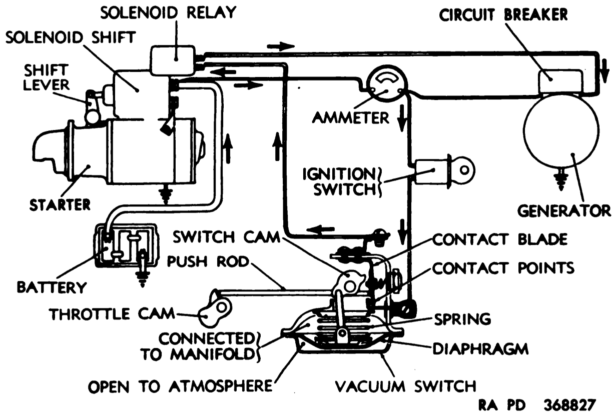

SOLENOID RELAY
CIRCUIT BREAKER
SOLENOID SHIFT
SHIFT LEVER
AMMETER
IGNITION SWITCH
STARTER
GENERATOR
SWITCH CAM
CONTACT BLADE
PUSH ROD
CONTACT POINTS
BATTERY
THROTTLE CAM
SPRING
CONNECTED TO MANIFOLD
DIAPHRAGM
OPEN TO ATMOSPHERE
VACUUM SWITCH
RA PD 368827

Figure 212. Vacuum switch control of solenoid shift.

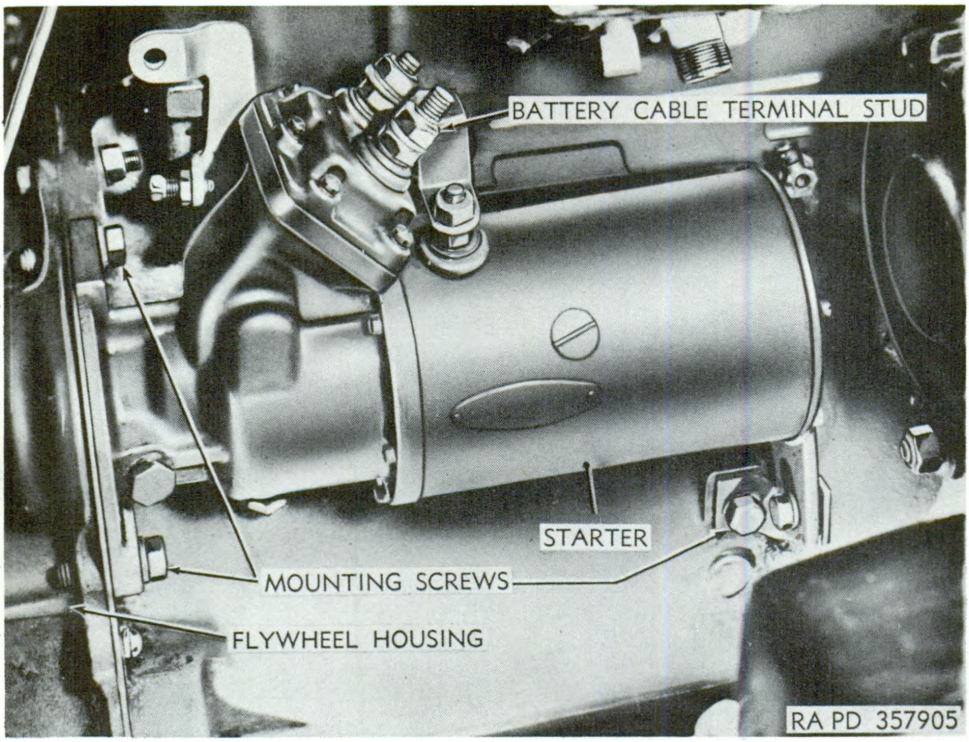


Figure 213. Waterproofed starter.

or less. After the engine starts, the generator voltage builds up and, as soon as the difference between the generator voltage and the battery voltage is 2.0 volts or less, the relay contact points open.

144. Waterproofing Starters

Vehicles that are expected to ford water deep enough to cover the starter have waterproofed starters. Such starters (which could have either a Bendix drive or an overrunning clutch) are completely sealed so no water can enter. Bearings are lubricated on original assembly and require no attention between overhauls. Figure 213 shows a completely sealed starter with an integral switch and a manually engaged drive with an overrunning clutch.

Section V. BATTERY IGNITION

145. Function

Ignition of the fuel-air mixture in the engine cylinder may be accomplished by either of two methods; by heat of compression as in diesel engines or by electric spark as in gasoline engines. Spark ignition may be subdivided into two classes: battery and magneto. These two systems are essentially the same. With either, the fundamental job is to step up low voltage to a much higher value, 15,000 to 20,000 volts, and to deliver the high voltage to the spark plugs with the proper timing. The high voltage is capable of pushing current through the high resistance set up by the pressure in the combustion chamber and across from one spark plug electrode to the other. The hot spark created ignites the fuel-air mixture. This section pertains to battery ignition, its theory and operation; paragraphs 151 through 159 describe magneto ignition.

146. Self-Induction

a. The principle of *electromagnetic induction* has been described in paragraph 119. When a wire is moved through a magnetic field, or a magnetic field is moved past a wire, the wire will have current induced in it. The magnetic field can be moved past the wire mechanically, or it can be made to move (if it is from an electromagnet) by turning the current on and off. This action causes the magnetic field to build up and collapse.

Any wire held in this magnetic field will, therefore, have current induced in it.

b. The turns of wire in the electromagnet itself will have current induced in them by the moving magnetic field. For example, figure 169 shows two loops, or turns, of an electromagnet. When current first starts to flow, it enters the first loop and a magnetic field begins to build up along with the increase of current. The magnetic field consists of circular lines of force surrounding the wire, and the lines of force move outward and cut through the adjacent loops. These lines of force, as they cut throught the adjacent loops of wire, produce a current in these adjacent loops. It is important to note that the induced currents oppose the original currents. This can be determined by use of the left-handed rule, imagining the expanding lines of force from the first loop cutting across the second loop. Note that the lines of force cut across the second loop in a direction that will induce an opposing current.

c. Actually, it would be more correct to say that an opposing voltage is induced. The voltage must come first, then the current. That is, to return to fundamentals for a moment, there must first be an electron concentration and an electron shortage in a circuit for current (or electrons) to flow. With this electron unbalance (or this voltage) in existence, there will be an electric current. The opposing or countervoltage that is self-induced by the expanding lines of force is opposite in direction to the voltage from the external source that is forcing current through the loops of the electromagnet.

d. The effect of the countervoltage is to prevent an instantaneous magnetic buildup. That is, the countervoltage slows down the rate at which the current flow can increase and the magnetic field can expand and strengthen. The increase of the magnetic field produces the countervoltage; this countervoltage opposes further increases of current flow. However, the external voltage is stronger and therefore continues to increase the strength of the current until it reaches the value determined by the resistance of the circuit, including the electromagnet.

e. Actually, in most electromagnets the countervoltage effect slows buildup time only a very small fraction of a second. But with electromagnets of many hundreds or thousands of turns, it does take an appreciable time for buildup to occur. In the ignition system, if buildup time took too long, the high-voltage sparks would not be produced fast enough and high engine speed could not be attained. However, the ignition coil can function with adequate speed for normal ignition even at high speed.

f. Not only does the countervoltage appear during buildup, it also occurs during magnetic collapse. That is, when the electromagnet is disconnected from the voltage source so that the current stops flowing, the magnetic field collapses. By "collapse" is meant that the lines of force are moving *toward* the wires from which they came. The lines of force are moving in the reverse direction from when the magnetic buildup took place. This means that the countervoltage induced in the adjacent wire loops will also be reversed. Since it is reversed, it is *in the same direction as the original voltage.* The countervoltage opposes a decrease of current. The countervoltage always opposes any change in voltage, any change in current flow. During buildup, it opposes the increasing current flow. During collapse, it opposes any decreasing current flow.

g. The effect of countervoltage during magnetic collapse can cause severe arcing at the switch, or contacts, used to open the circuit of the electromagnet. For instance, in A, figure 214, when the contacts are opened, the countervoltage produced by the collapsing magnetic field will be great enough, if the electromagnet has enough turns, to push current across the opening contacts so that an arc occurs. This arc not only tends to burn the contacts, it also slows down the speed of magnetic-field collapse. The use of a capacitor (formerly referred to as a *condenser*) across the contacts protects them from arcing and speeds up the magnetic-field collapse, as explained in paragraph 147.

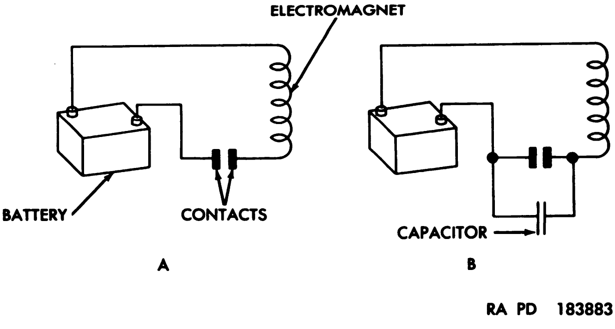


Figure 214. Capacitor in circuit of electromagnet.

147. Capacitor Action

a. The capacitor has the capacity to store electrical charges briefly, and it therefore acts as a storage place for the surge of current caused by the countervoltage during magnetic collapse. Instead of arcing across the contacts, the current enters the capacitor.

b. The capacitor consists essentially of a pair of metallic plates separated by insulating material. In actual construction, the automotive capacitor is made up of two long strips of lead or aluminum foil wrapped into a winding with insulating paper between them. One strip of foil is connected to the capacitor can, the other is attached to a terminal.

c. In operation, the foil strips serve as a large area into which free electrons (electric current) can move. For instance, suppose that the contacts in B, figure 214, are just opening. This interrupts the current from the battery, and a magnetic collapse starts. With the movement of the collapsing lines of force across the turns of wire in the electromagnet, a countervoltage is produced in the electromagnet which attempts to continue the current flow. However, instead of this current flowing across the contacts in an arc, it flows into the capacitor. One of the foil strips (the one connected to the negative side) accepts large numbers of free electrons (flow of current). These free electrons flow onto the strip. As they do so, they give the strip a negative charge. This negative charge repels electrons from the other strip so that it becomes positive.

d. The capacitor tends to prevent an arc at the contacts. It also tends to hasten the collapse of the magnetic field. It does this because it soon becomes charged and thereby opposes any further current flow. In a sense, it acts like a spring to bring the current to a quick stop.

e. If no other external action took place to change the conditions, the capacitor would then discharge back into the electromagnet. As it did this, there would be a magnetic buildup (opposed by a countervoltage), followed by a magnetic collapse as the capacitor completed discharging (again opposed by a countervoltage). The result would be a rapid swing of current back and forth as it moved first in one direction and then in the other. Each time the capacitor would charge and discharge. And each time the amount of current would be a little less, as some of it would be used up in heating the electromagnet. Shortly, the alternations would stop. In actual operation, they would end in a fraction of a second.

148. Mutual Induction

a. If a second winding were placed close to the first and connected to a lamp of the proper size, as shown in figure 215, we could see the effect of the magnetic buildup and collapse as the contacts are closed and opened. For instance, when the contacts are closed, a magnetic field builds up. This magnetic field, in building up, moves across the second (or secondary) winding. This induces a voltage in the secondary winding so that a current flows through it and through the lamp. If the lamp is of the right size, it will light up momentarily; it will light up only for a moment because the magnetic field does not take long to build up.

b. When the contacts are opened, the magnetic field collapses and again moves across the secondary winding, inducing a voltage that causes the lamp to flash momentarily.

c. With a capacitor (fig. 215), the lamp would be brighter as the contacts opened. The reason for this is that the capacitor speeds up the magnetic collapse. The lines move faster across the secondary winding in collapsing because of the capacitor effect. Faster-moving lines means a higher voltage and more current which, in turn, means a brighter light.

149. Ignition System

a. General. Figure 216 shows most of the essentials of an ignition system. Not shown in the illustration are the means of opening and closing the contacts and the means of distributing the induced high-voltage surges from the secondary to the spark plugs in the various cylinders. An actual schematic diagram of an ignition is shown in figure 216 and what the various components in the system do can be noted.

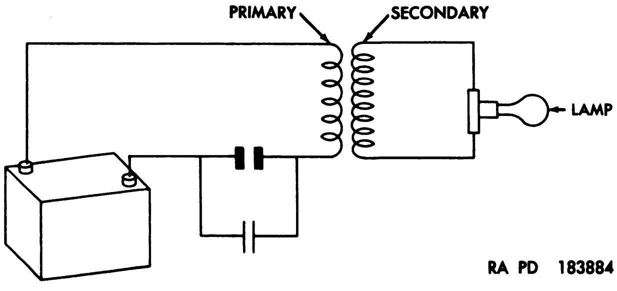


Figure 215. Mutual induction between two windings.

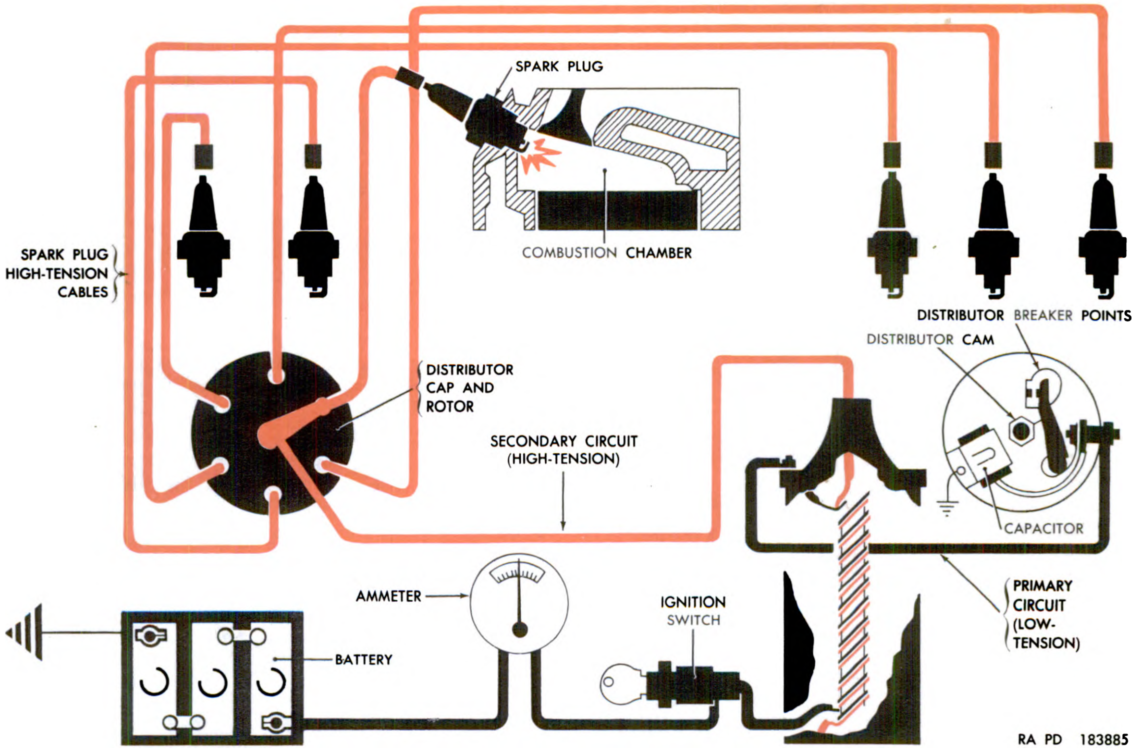

SPARK PLUG
COMBUSTION CHAMBER
SPARK PLUG HIGH-TENSION CABLES
DISTRIBUTOR CAP AND ROTOR
SECONDARY CIRCUIT (HIGH-TENSION)
DISTRIBUTOR BREAKER POINTS
DISTRIBUTOR CAM
CAPACITOR
PRIMARY CIRCUIT (LOW-TENSION)
AMMETER
BATTERY
IGNITION SWITCH
RA PD 183885

Figure 216. Schematic wiring circuits of an ignition system.

b. Battery. The battery and generator furnish the source of voltage and current for the ignition system. The battery is required when first starting, but, after the vehicle starts moving, the generator takes up the ignition load.

c. Ammeter. Most electric circuits in the vehicle are connected through the ammeter to the battery. This enables the driver to determine at a glance whether the generator or the battery is carrying the load; that is, whether the battery is being charged or discharged.

d. Ignition Switch. The ignition switch enables the driver to turn the ignition on for starting and running the engine and to turn it off to stop the engine.

e. Ignition Coil. The ignition coil consists of a primary winding of a few hundred turns of relatively heavy wire (No. 18 is a commonly used size) which is about 0.04 inch in diameter plus a secondary winding of many thousands of turns of a very fine wire (No. 38 is a commonly used size) which is about 0.004 inch in diameter, both assembled around a soft iron core and inclosed by a metal case topped with an insulating cap which carries the terminals (fig. 217). Since the countervoltage induced by the collapsing magnetic field is about the same value for each turn, the fact that the secondary has many more turns means that the secondary voltage will go much higher than the primary voltage. With a turn

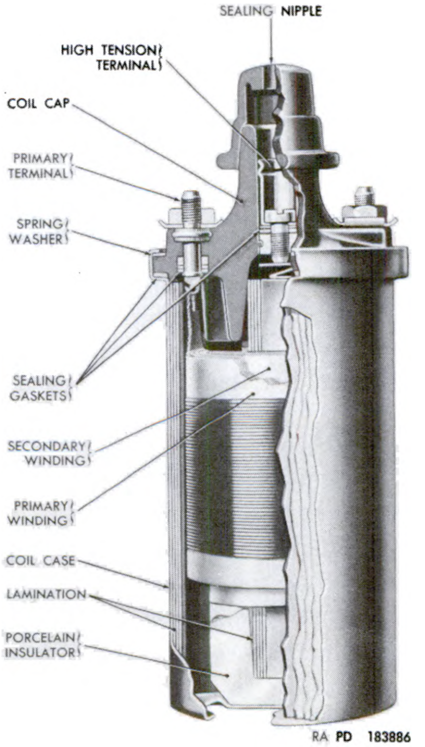

SEALING NIPPLE
HIGH TENSION TERMINAL
COIL CAP
PRIMARY TERMINAL
SPRING WASHER
SEALING GASKETS
SECONDARY WINDING
PRIMARY WINDING
COIL CASE
LAMINATION
PORCELAIN INSULATOR
RA PD 183886

Figure 217. Ignition coil—sectional view.

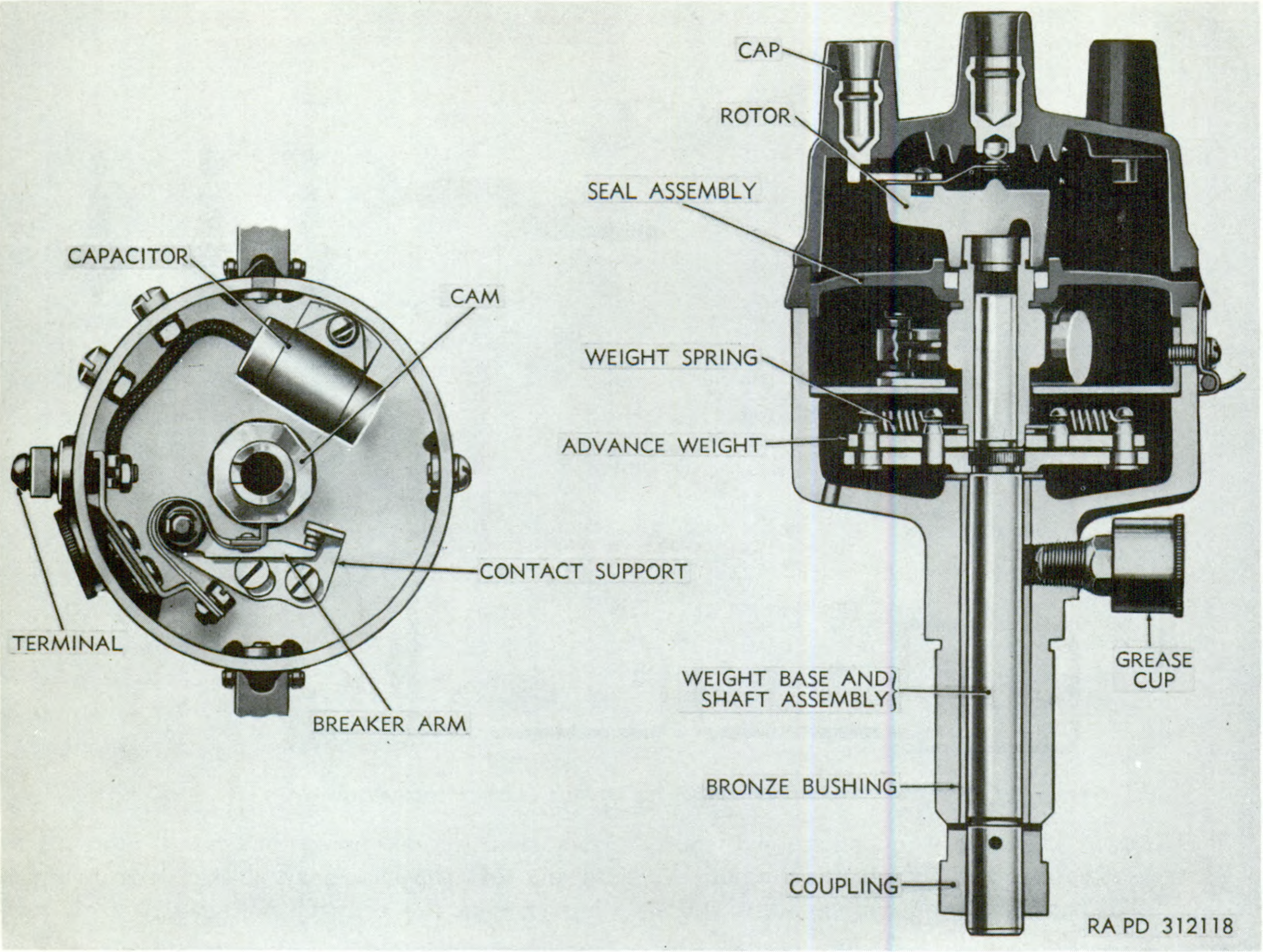

CAP
ROTOR
SEAL ASSEMBLY
CAPACITOR
CAM
WEIGHT SPRING
ADVANCE WEIGHT
CONTACT SUPPORT
TERMINAL
GREASE CUP
WEIGHT BASE AND SHAFT ASSEMBLY
BREAKER ARM
BRONZE BUSHING
COUPLING
RA PD 312118

Figure 218. Distributor—top view (without cap) and side sectional view.

ratio of 100:1 (100 turns in secondary to 1 turn in primary), the secondary voltage could go 100 times as high as the primary. Since the countervoltages induced in the primary (by the rapid collapse of the magnetic field brought about by capacitor action) may reach 200 volts or more, the secondary voltage could reach 20,000 volts. This high voltage is carried through the ignition distributor and distributed to the correct spark plug.

f. Ignition Distributor.

(1) The ignition distributor has several jobs to do in the ignition system. First, it must close and open the primary circuit to produce the magnetic buildup and collapse in the ignition coil. Second, it times these actions so the resultant high-voltage surges from the secondary will be produced at the right time. Third, it must direct the high voltage surges to the proper spark plugs. See figures 218 and 219 for views of a typical distributor.

(2) The primary circuit through the distributor consists, essentially, of a set of contacts and a capacitor connected across the contacts. The contacts are closed by spring pressure and opened by a cam driven through the distributor shaft from a gear on the engine camshaft. Often, the oil pump is driven from the same gear. As the cam rotates, the cam lobes move around under the contact arm, causing the contacts to open and close.

(3) The secondary circuit through the distributor consists of a rotor mounted on top of the cam and a cap with high-tension terminals. In action, the rotor turns with the cam, connecting through its metal segment between the center high-tension terminal and the various outer high-

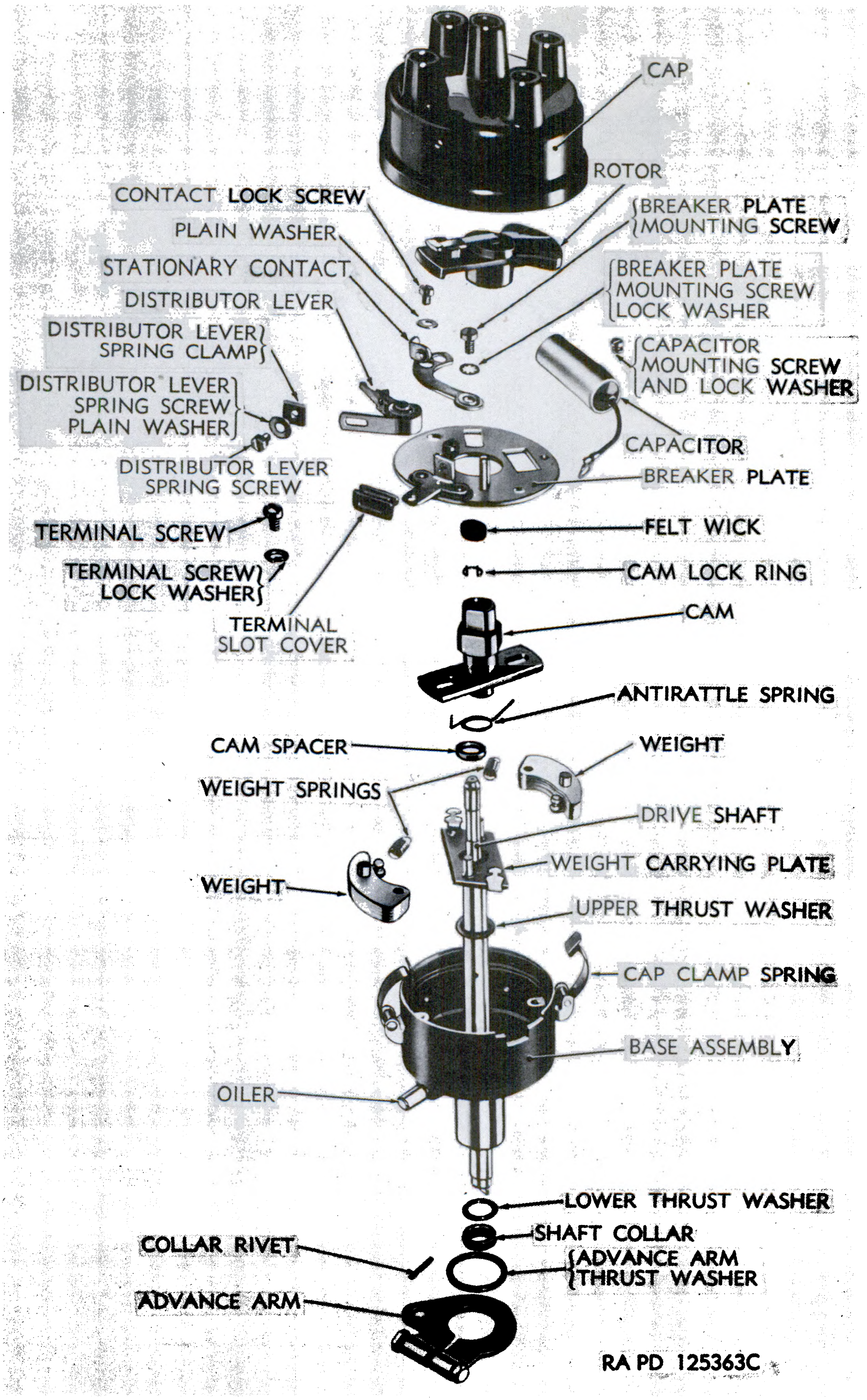

CAP
ROTOR
CONTACT LOCK SCREW
PLAIN WASHER
BREAKER PLATE MOUNTING SCREW
STATIONARY CONTACT
BREAKER PLATE MOUNTING SCREW LOCK WASHER
DISTRIBUTOR LEVER
DISTRIBUTOR LEVER SPRING CLAMP
CAPACITOR MOUNTING SCREW AND LOCK WASHER
DISTRIBUTOR LEVER SPRING SCREW PLAIN WASHER
CAPACITOR
DISTRIBUTOR LEVER SPRING SCREW
BREAKER PLATE
TERMINAL SCREW
FELT WICK
TERMINAL SCREW LOCK WASHER
CAM LOCK RING
TERMINAL SLOT COVER
CAM
ANTIRATTLE SPRING
CAM SPACER
WEIGHT
WEIGHT SPRINGS
DRIVE SHAFT
WEIGHT CARRYING PLATE
WEIGHT
UPPER THRUST WASHER
CAP CLAMP SPRING
BASE ASSEMBLY
OILER
LOWER THRUST WASHER
SHAFT COLLAR
COLLAR RIVET
ADVANCE ARM THRUST WASHER
ADVANCE ARM
RA PD 125363C

Figure 219. Distributor—disassembled view.

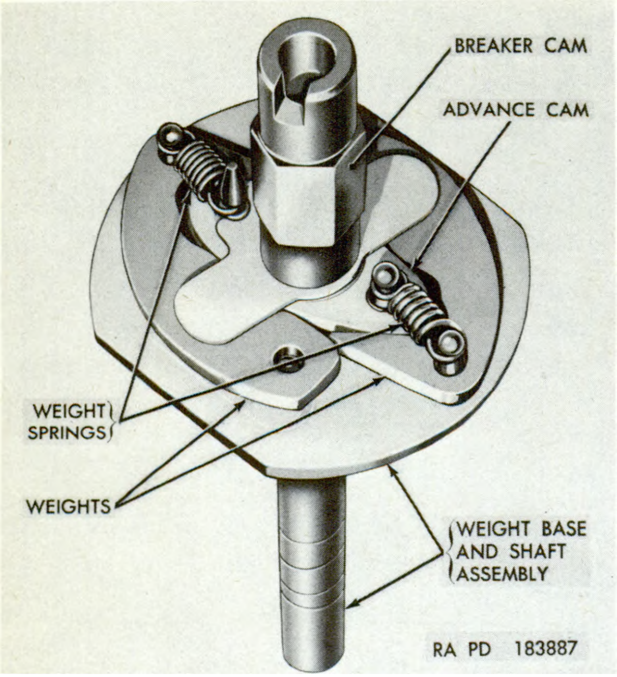


Figure 220. Centrifugal advance mechanism.

tension terminals. This directs the high voltage surges from the coil (which enter through the center high-tension terminal) to the various engine spark plugs (which are connected, in firing order, to the outer high-tension terminals).

(4) Spark advances are required (par. 11*e* and *f*) so that the spark will occur in the combustion chamber at the proper time in the compression stroke. At high speed, the spark must appear earlier so the fuel-air mixture will have ample time to burn and give up its energy to the piston. At part throttle, when the fuel-air mixture is less highly compressed, a spark advance is required to ignite the slower-burning mixture in ample time for it to burn and deliver its power. Centrifugal and vacuum advance mechanisms produce these advances.

(5) The centrifugal advance mechanism is located in the distributor housing and consists essentially of a pair of weights mounted on pins on a weight base and linked by weight springs to the advance cam (fig. 220). When idling, the springs hold the advance cam in a "no-advance" position. As speed increases, the centrifugal force on the weight (fig. 221) causes them to move out. This action forces the toggles on the weights to move against the advance cam so the cam is pushed ahead against the spring tension. As the advance cam turns ahead, the breaker cam lobes open and close the contacts earlier in the cycle. This advances the spark.

(6) The vacuum advance mechanism makes use of a vacuum chamber connected to the intake manifold and a vacuum diaphragm linked to the breaker plate assembly (fig. 222). The breaker plate is supported so it can turn back and forth a few degrees. When there is a wide-open throttle and little or no vacuum in the intake manifold, a full measure of fuel-air mixture is entering the cylinders and no spark advance beyond the centrifugal advance is needed. But when the throttle is partially closed, part of the fuel-air mixture is throttled off and the mixture entering the cylinders is less highly compressed. For satisfactory combustion, the spark must be further advanced beyond the advance produced by the centrifugal mechanism. To secure this additional advance, the vacuum line admits manifold vacuum to the vacuum passage, thereby allowing atmospheric pressure to push the diaphragm inward, compressing the return spring. This movement, through the linkage from the diaphragm, causes the breaker plate to be turned ahead so that the contacts are opened and closed earlier in the cycle. This advances the spark. Usually, the vacuum line is tapped into the carburetor just at the upper edge of the throttle valve when it is closed. This permits no advance on idle but causes a vacuum advance as the throttle valve is opened so its edge moves past the vacuum passage.

(7) The vacuum-controlled brake (fig. 223) is another method of controlling the spark advance. This distributor has a centrifugal advance mechanism much like the one described in (5) above. In addition, it has a vacuum piston brake. The piston is held out by atmospheric

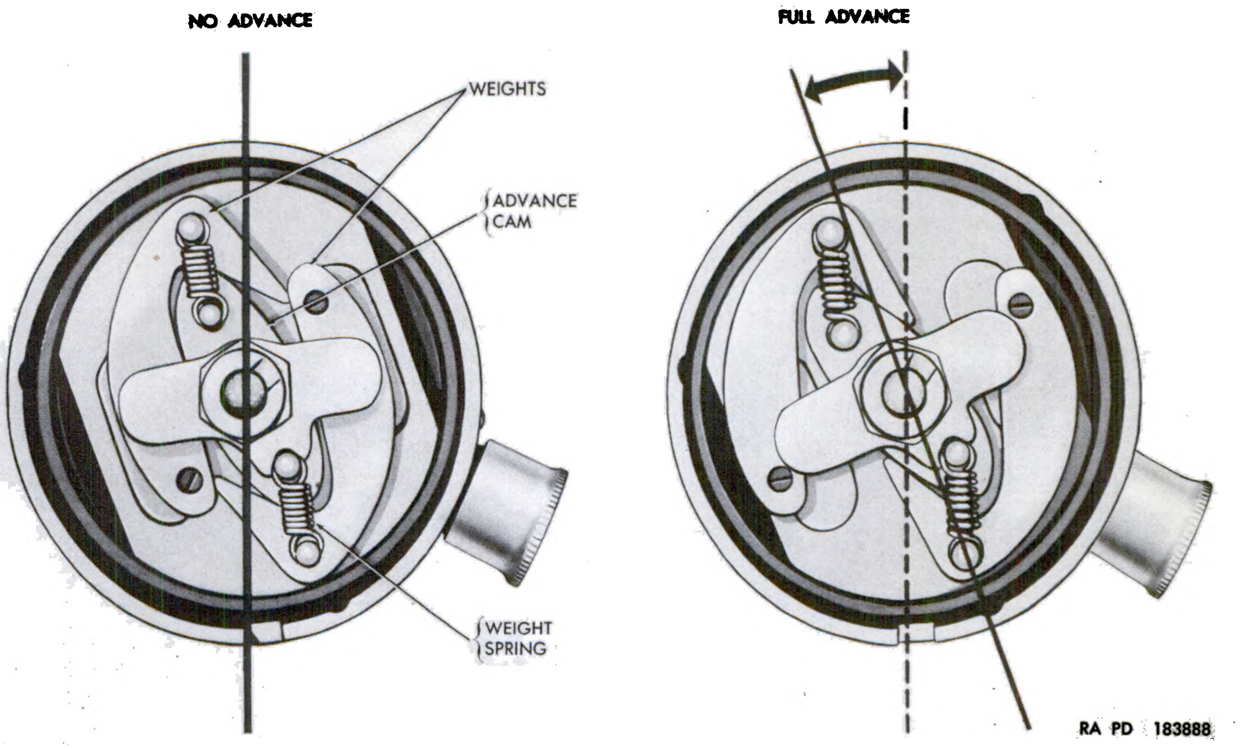


Figure 221. Action of centrifugal advance.

pressure when there is intake manifold vacuum (under part-throttle conditions) so that the centrifugal advance mechanism can provide further advance. But, with wide-open throttle and pressure approaching atmospheric in the intake manifold, the piston spring can push the piston in against the advance plate of the advance mechanism, thus reducing the amount of advance. The effect is the same as with the centrifugal and vacuum advance mechanisms described in (5) and (6) above; there is more advance at part throttle than there is at full throttle at any particular speed.

(8) A still different method of achieving the proper advance for speed and throttle opening is to use a vacuum advance mechanism (fig. 222) on the distributor, and to connect the vacuum line at two points in the carburetor, one at the throttle-valve as described in (6) above and the other at the carburetor venturi. The vacuum at the carburetor venturi is proportional to engine speed and at high engine speed there would be more vacuum and more vacuum advance. This advance combines with the vacuum advance resulting from intake manifold vacuum to produce full advance control.

g. Multiple Contacts in Distributors.

(1) *General.* Distributors may have more than one set of contacts. Some distributors use two sets in parallel for longer contact closing and higher magnetic strength of the coil. Others may use two sets for alternate firing of cylinders. Still others have two sets for dual ignition or for operation of two semi-independent ignition systems listed in (2) through (5) below.

(2) *Parallel operation.* To counteract the bounce, or chatter, of the breaker arm and to prevent overload of the contact points (fig. 224), two breakers can be connected in parallel and adjusted to open at the same time. If one pair of contacts has a tendency to bounce open at high speed, it is probable that the other pair will not bounce at exactly the

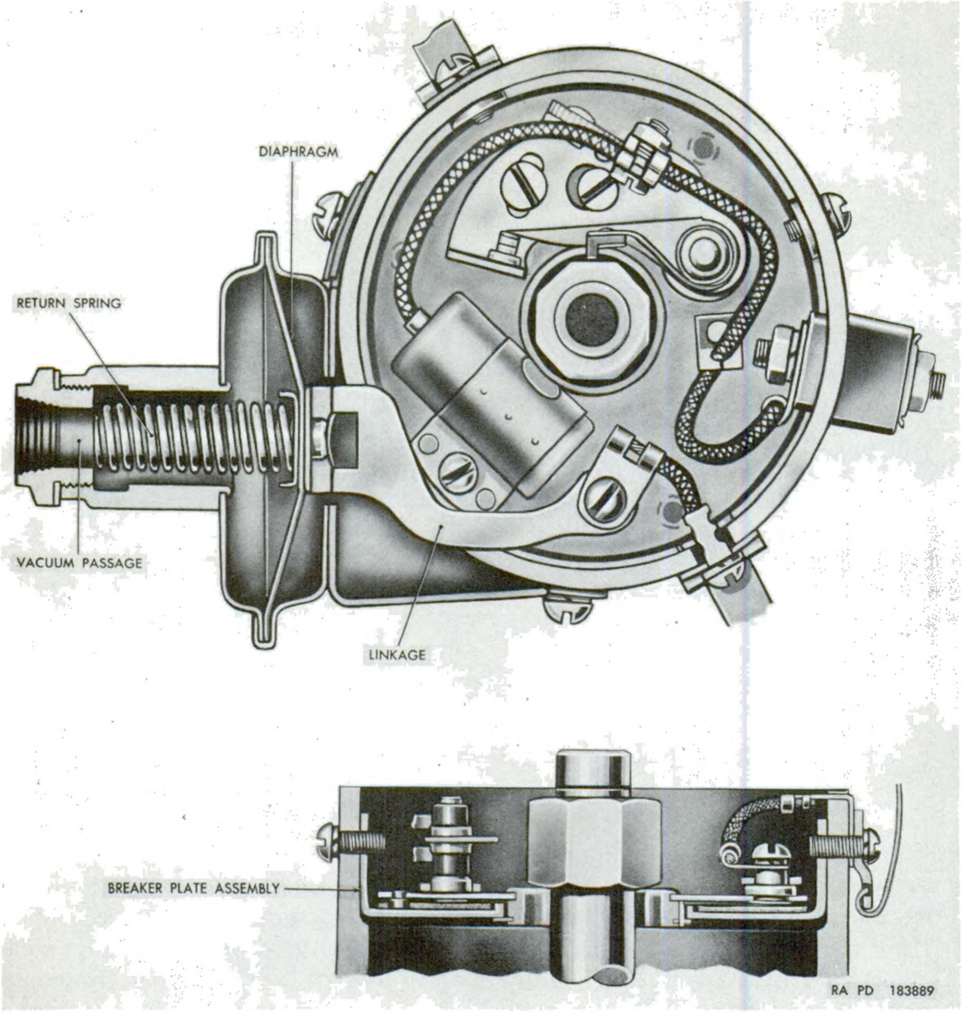


Figure 222. Vacuum advance mechanism.

same instant, and therefore the circuit will be closed much more positively than it would be with only one pair of contacts. The breaker arms also can be connected in parallel but made to operate progressively; that is, they are so set with respect to the cam lobes that one arm opens its contacts slightly before the other. The circuit is not actually broken until the second set of contacts open. Both sets of contacts are open for a shorter period of time than they are in simultaneous operation. This allows the ignition coil a slightly longer period of time in which to build up. The breakers are arranged for progressive parallel operation.

(3) *Alternate operation.* This is another arrangement that increases the time of contact and allows better magnetization of the coil. The two pairs of contacts still operate electrically in parallel, but use a cam with only half as many lobes as there are cylinders to be fired. The breakers are so arranged around the cam that one pair of contacts will close almost immediately after the other pair has opened. Thus, the two sets of breaker contacts almost overlap each other's movements so there is no waste of time. Shortly after one pair of contacts opens the circuit, the other pair closes it, so the coil can start to build up at once in preparation for the next spark. One set of contacts operates for half the

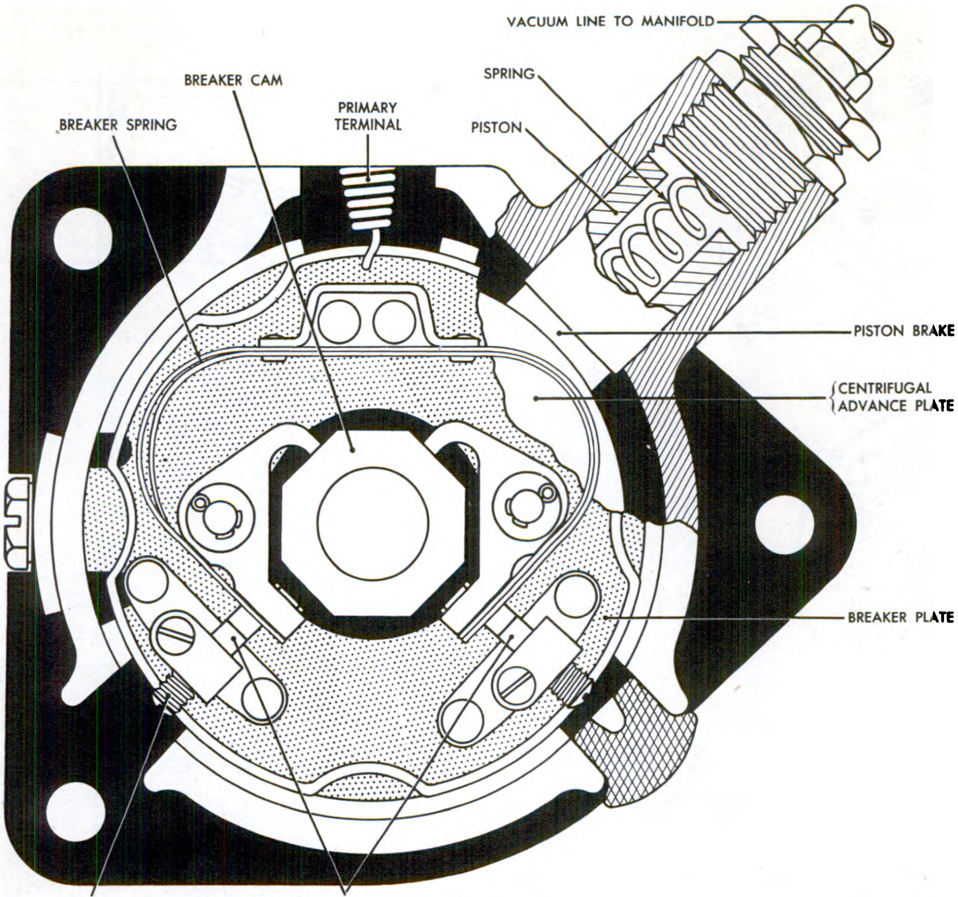

VACUUM LINE TO MANIFOLD
SPRING
BREAKER CAM
PRIMARY TERMINAL
BREAKER SPRING
PISTON
PISTON BRAKE
CENTRIFUGAL ADVANCE PLATE
BREAKER PLATE
CONTACT ADJUSTMENT
BREAKER CONTACTS
RA PD 183890

Figure 223. Vacuum brake spark advance mechanism.

cylinders and the other set for the other half. Figure 225 shows the breaker arms set for alternate operation.

(4) *Two-circuit operation.*

(*a*) Another breaker arrangement, very similar in appearance to the one used for alternate operation ((3) above), is used with two separate coils for firing a large number of spark plugs. The breaker contacts operate alternately, but have no electrical connection between them except their common ground. In effect, this ignition interrupter permits two separate ignition systems; one system operating for one half of the cylinders and the other system for the other half. Here, the relation between the two sets of contacts is one of timing only, so that each will operate at the correct instant for the cylinders it serves.

(*b*) The distributor must take care of the two circuits. Figure 226 shows the usual design of a distributor in which the two circuits are combined. The high-tension lead from one coil enters the center of the distributor head at terminal A, figure 226, while the high-tension lead from the other coil enters at another terminal B, figure 226, which is connected to a small ring that surrounds the central terminal. Two separate segments are molded within a double arm rotor, each one in contact with one of the high-tension terminals. One rotor segment completes its circuit to alternate spark-plug terminals in the distributor cap, the other rotor segment taking the intervening terminals. Thus, there are two separate secondary circuits, A and B, figure 226, each furnishing current to half the spark plugs. The sparks from each coil are produced in exactly the same

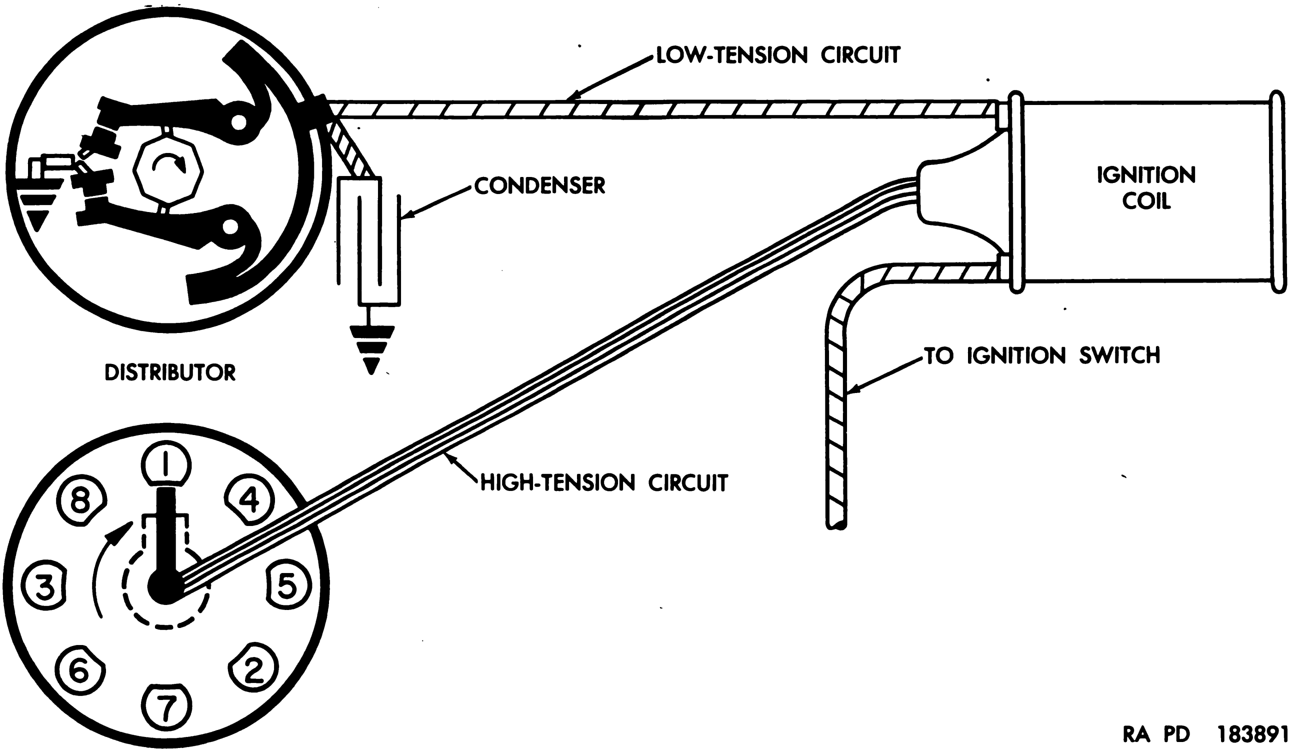

LOW-TENSION CIRCUIT
CONDENSER
IGNITION COIL
DISTRIBUTOR
TO IGNITION SWITCH
HIGH-TENSION CIRCUIT
1
8
4
3
5
6
2
7
RA PD 183891

Figure 224. Double contacts arranged for parallel operation.

way as they are in a single system since each coil has its own set of breaker contact points.

(*c*) Two-circuit operation is particularly adaptable to V-type engines, with each set of contacts taking care of one bank of cylinders. Figure 227 shows an arrangement for a V–12 engine. Since each set of breaker contacts is electrically independent of the other, the breakers require synchronizing for proper operation. On some V-type engines the two breaker arms open at irregular intervals, and therefore the manufacturer's specifications should be checked before any attempt is made to adjust the contact points.

(5) *Dual* (*twin*) *ignition.* Practically all automobiles have single ignition (one spark plug in each cylinder), although dual ignition has been used to advantage. No particular new theory is involved in producing and delivering current to the spark plugs in dual ignition. The principal difference is the use of two sparks to fire the fuel charge at two separated points within the same cylinder. If two sparks are delivered at widely separated points at the same instant, the fuel charge will start to burn from two

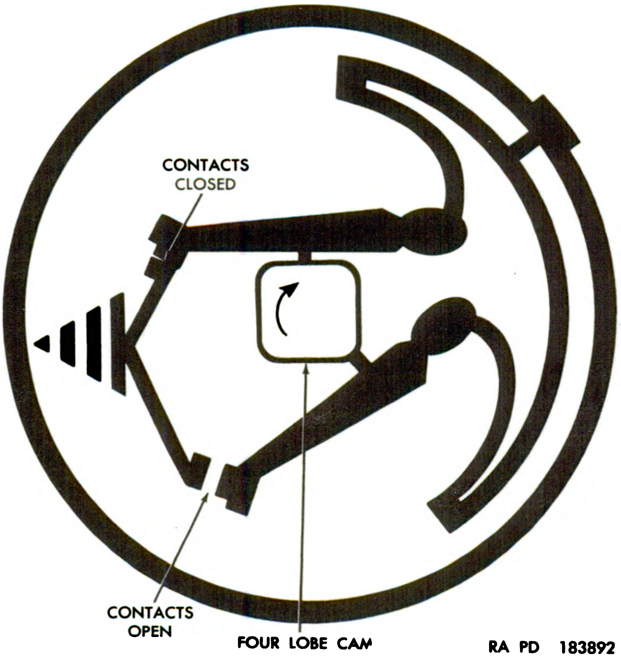

CONTACTS CLOSED
CONTACTS OPEN
FOUR LOBE CAM
RA PD 183892

Figure 225. Double contacts arranged for alternate operation.

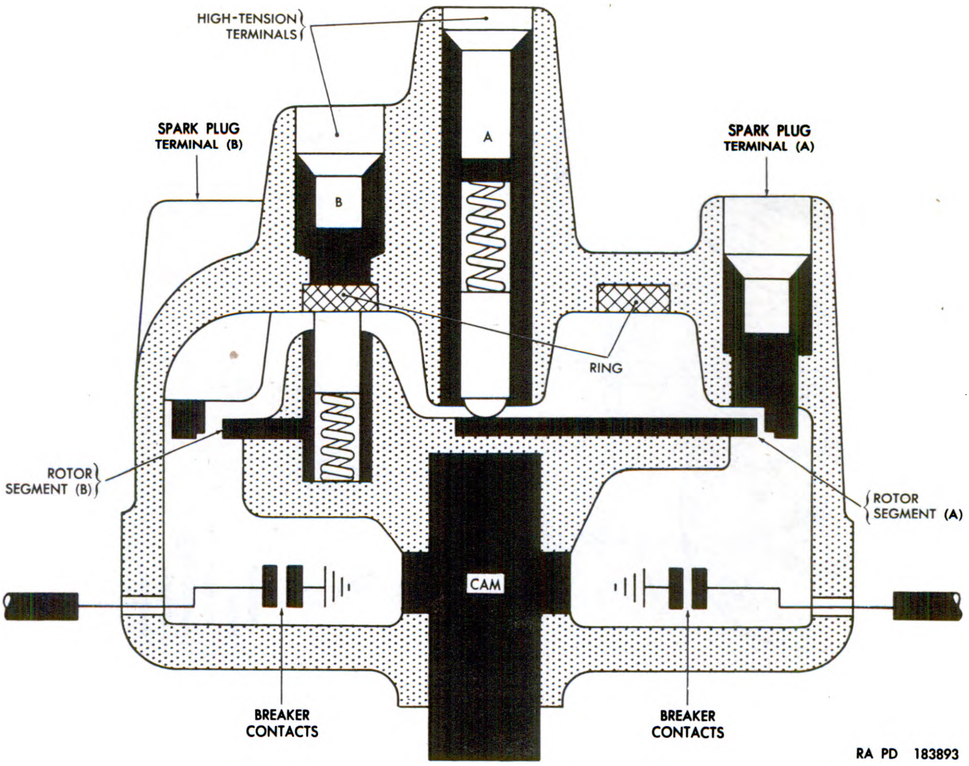

HIGH-TENSION TERMINALS
SPARK PLUG TERMINAL (B)
SPARK PLUG TERMINAL (A)
A
B
RING
ROTOR SEGMENT (B)
ROTOR SEGMENT (A)
CAM
BREAKER CONTACTS
BREAKER CONTACTS
RA PD 183893

Figure 226. Two-circuit distributor construction.

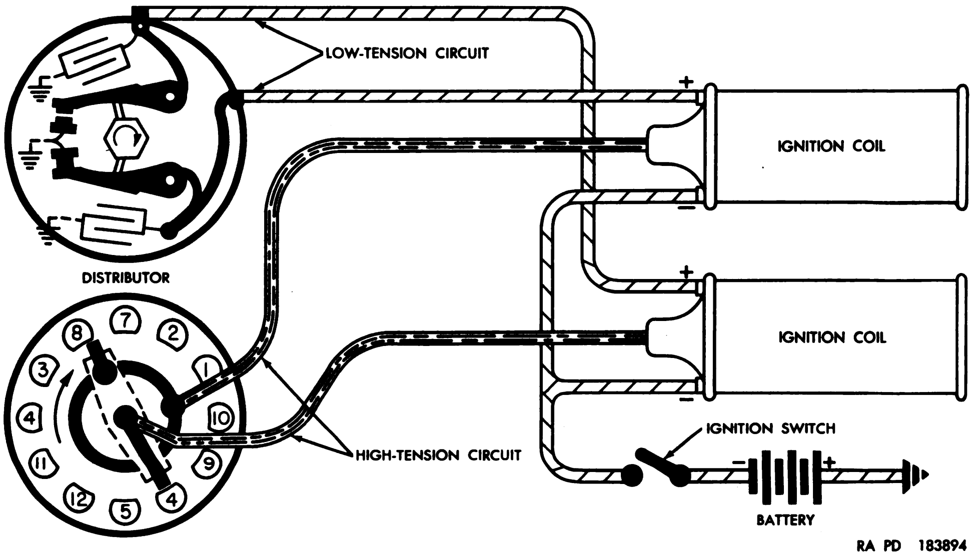

LOW-TENSION CIRCUIT
DISTRIBUTOR
IGNITION COIL
IGNITION COIL
+
−
+
−
8
7
2
3
1
4
10
11
9
12
5
4
HIGH-TENSION CIRCUIT
IGNITION SWITCH
BATTERY
−
+
RA PD 183894

Figure 227. Two-circuit system for V–12 engine.

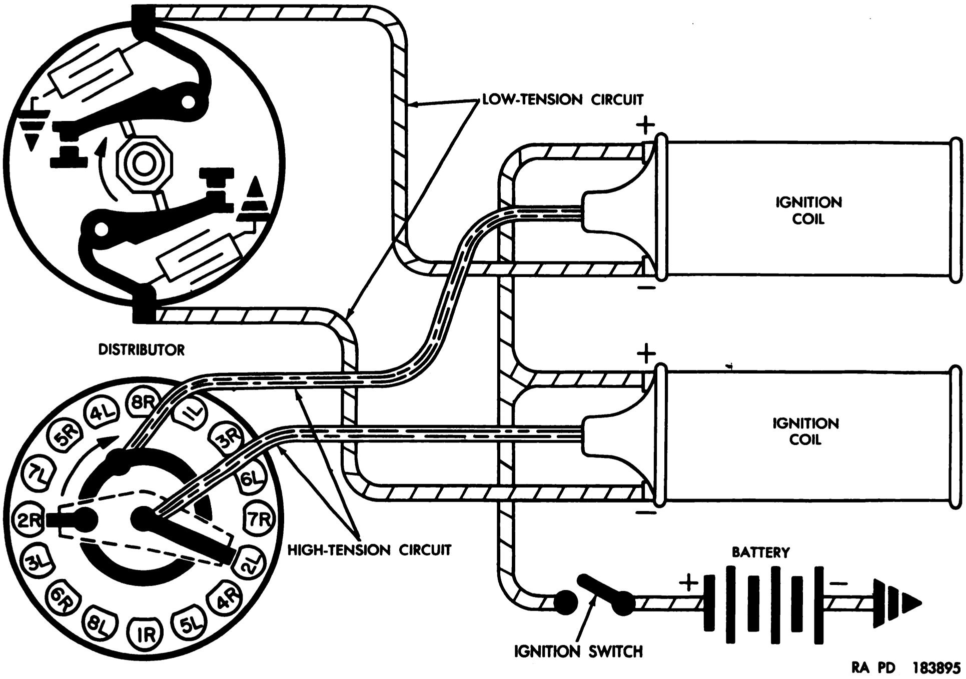

LOW-TENSION CIRCUIT
+
IGNITION COIL
−
DISTRIBUTOR
+
IGNITION COIL
−
8R
1L
3R
6L
7R
2L
4R
5L
1R
8L
6R
3L
2R
7L
5R
4L
HIGH-TENSION CIRCUIT
BATTERY
+
−
IGNITION SWITCH
RA PD 183895

Figure 228. Dual ignition system for 8-cylinder engine.

points and meet in the center, thus securing more rapid and complete combustion. The firing of two spark plugs in each cylinder from one current source is sometimes called *twin ignition*. The dual system (fig. 228) is provided with two coils and two breaker arms operating on two circuits to supply sparks to two sets of spark plugs. To obtain the full advantage of dual ignition, the breaker contacts must be synchronized to fire two sparks simultaneously in each cylinder. The rotor segments will then deliver sparks to two opposite terminals in the distributor head which are connected on two spark plugs within the same cylinder. Each rotor segment fires alternate terminals around the head; one segment firing the spark plugs on the right side of the cylinders and the other segment firing the spark plugs on the left side of the cylinders.

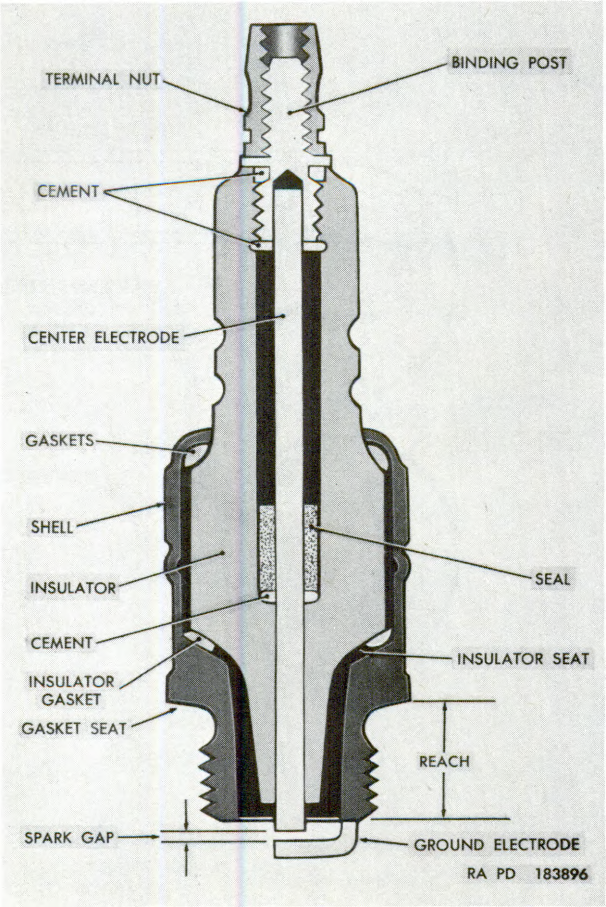

TERMINAL NUT
BINDING POST
CEMENT
CENTER ELECTRODE
GASKETS
SHELL
SEAL
INSULATOR
CEMENT
INSULATOR SEAT
INSULATOR GASKET
GASKET SEAT
REACH
SPARK GAP
GROUND ELECTRODE
RA PD 183896

Figure 229. Typical spark plug—sectional view.

h. Spark Plugs. The spark plug (fig. 229) consists essentially of a porcelain insulator in which there is an insulated electrode supported by a metal shell on which there is a grounded electrode. Several types of spark plugs have been used. In essence, they have the simple purpose

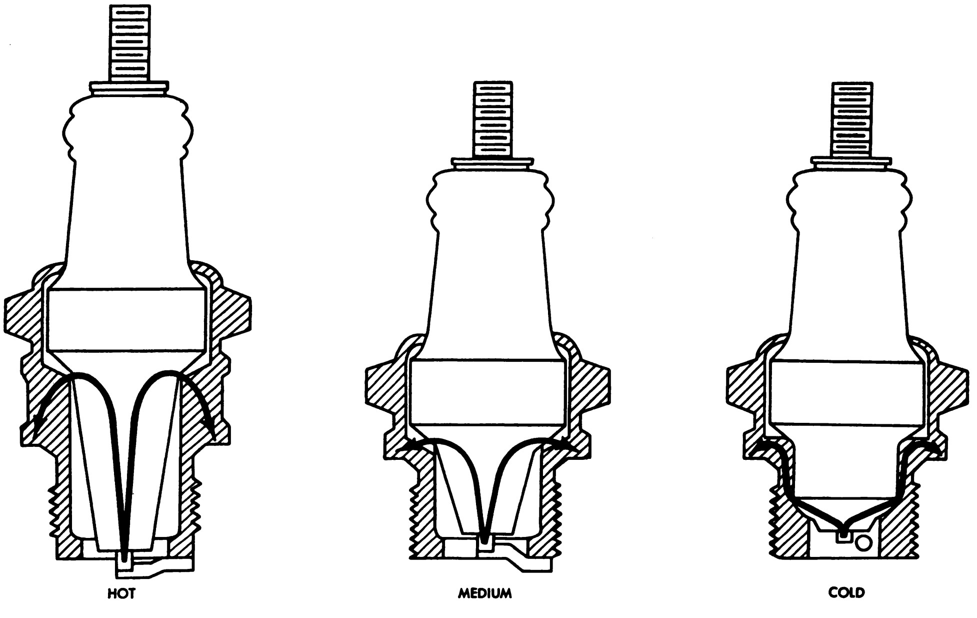


Figure 230. Heat paths in different plugs.

of supplying a fixed gap in the cylinder across which the high-voltage surges from the coil must jump, after passing through the distributor. The heat range of spark plugs is very important since a plug that runs too cold will accumulate heavy coatings of carbon (unburned gasoline), while a plug that runs too hot will soon burn up. Figure 230 illustrates the meaning of heat range. When the heat path from the center electrode to the cylinder head is long, the plug will run hotter. When the path is short, the heat can escape more readily and the plug runs cooler.

i. Ignition Timing.

(1) The timing of the ignition can be adjusted to compensate for wear or changes made during repair. Most engines have timing marks (figs. 231 and 232) on the flywheel or the crankshaft vibration damper. These marks must aline properly with a pointer just at the instant that No. 1 cylinder fires (spark ocurs at No. 1 plug). Two commonly used methods of setting ignition timing are the test light method and the neon timing light method. With the test light method, a low-voltage light is connected across the contacts (cap off) and the engine then cranked (ignition switch on) until the contacts just begin to separate the No. 1 firing position. The pointer and proper marking on the flywheel or damper should aline just as the light comes on (to indicate contact separation). The second method consists of using a neon timing light connected to No. 1 spark plug terminal (fig. 233). The neon light will flash each time the No. 1 spark plug fires, so that if it is directed at the flywheel or damper markings they will appear to stand still.

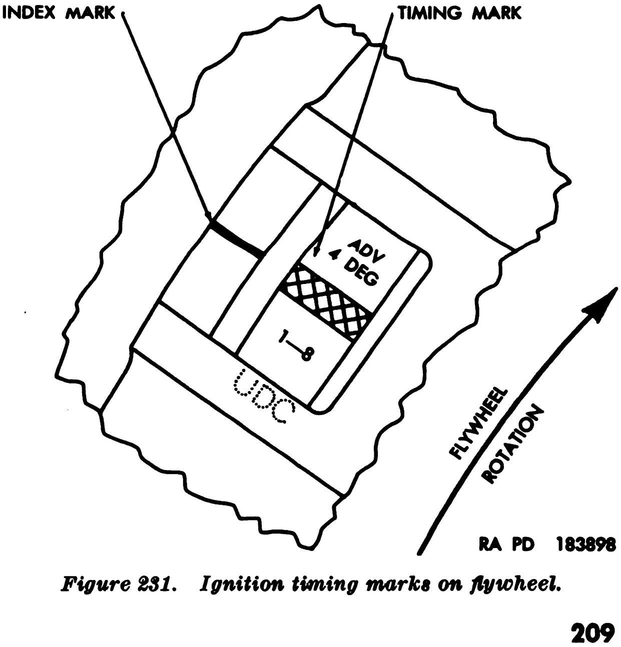


Figure 231. Ignition timing marks on flywheel.

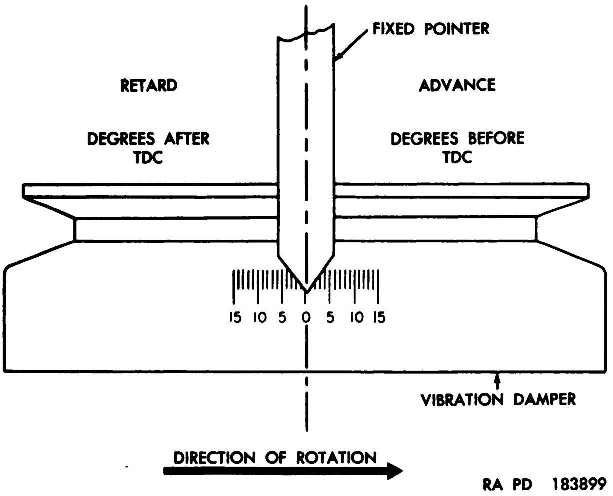

FIXED POINTER
RETARD
ADVANCE
DEGREES AFTER TDC
DEGREES BEFORE TDC
15 10 5 0 5 10 15
VIBRATION DAMPER
DIRECTION OF ROTATION
RA PD 183899

Figure 232. Ignition timing marks on vibration damper.

(2) The distributor can, in either case, be loosened in its mounting and turned one way or the other to adjust the timing. On multiple-breaker distributors, the breakers must first be synchronized. Refer to the applicable technical manual for specific information.

150. Waterproofing Ignition Systems

a. Since many vehicles must operate under very wet conditions and must be able to ford fairly deep waters, it is necessary to waterproof the ignition system. By that is meant that the system must be so watertight that, even thought the components are immersed, they can continue to function normally and will not suffer any damage.

b. The distributor and ignition coil (fig. 234) are sealed in a common housing and inclosed by a common cover. Figure 235 shows the assembly with the cover removed. This applicaion also has a means of ventilating the distributor, thus preventing the condensation of water and the formation of harmful chemicals. Otherwise, such chemicals might form due to the arcing that takes place between the rotor segment and the cap inserts at the outer high-tension terminals. The ventilation is accomplished by connecting two tubes to the distributor, one leading to the air cleaner (from which clean air can be obtained) and the other to the intake manifold. The intake manifold vacuum causes air to pass through the distributor from the air cleaner, thus keeping the distributor well ventilated.

c. The various leads in the ignition system (fig. 234) are inclosed in a watertight conduit. This conduit prevent moisture from getting to the leads with resultant insulation deterioration, also shorting or grounding caused by presence of water.

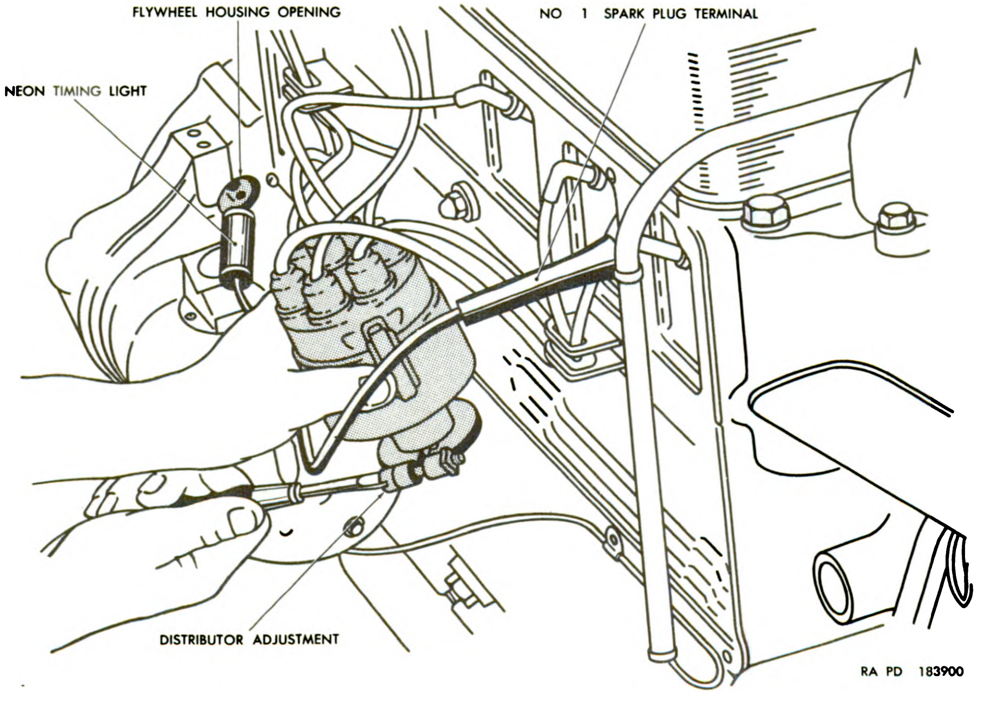

FLYWHEEL HOUSING OPENING
NO 1 SPARK PLUG TERMINAL
NEON TIMING LIGHT
DISTRIBUTOR ADJUSTMENT
RA PD 183900

Figure 233. Using a neon timing light.

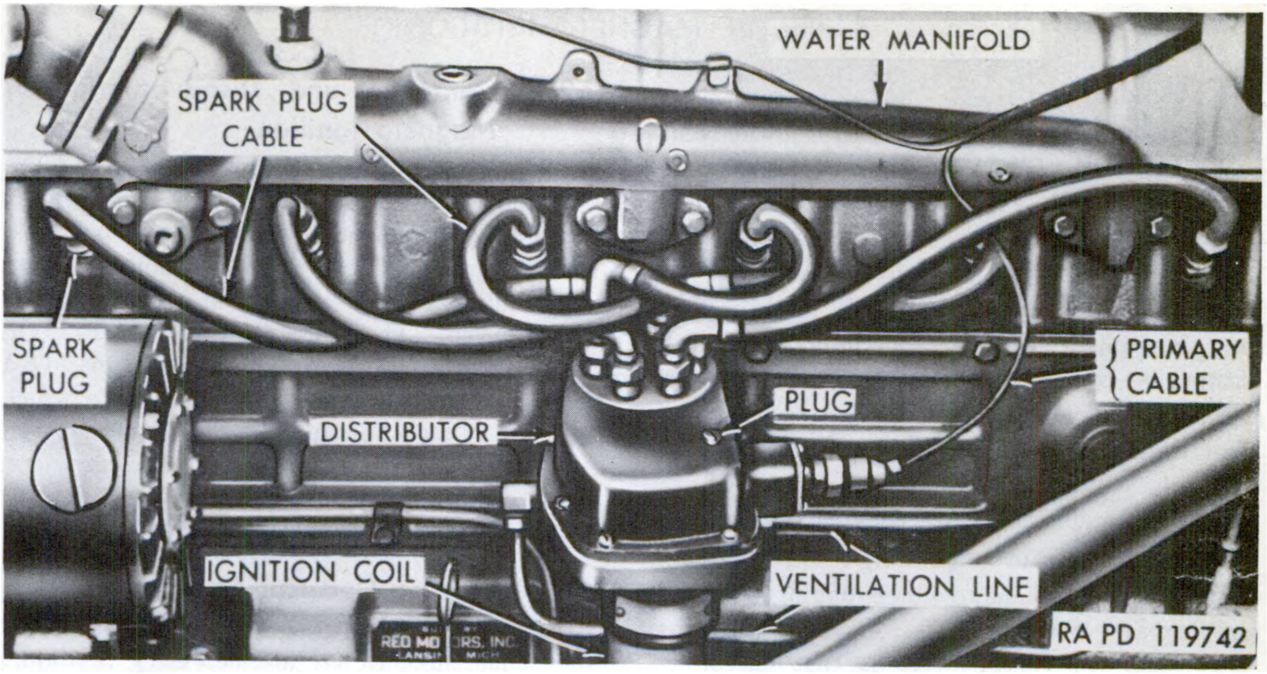

WATER MANIFOLD
SPARK PLUG CABLE
SPARK PLUG
PRIMARY CABLE
DISTRIBUTOR
PLUG
IGNITION COIL
VENTILATION LINE
RA PD 119742

Figure 234. Waterproofed ignition system.

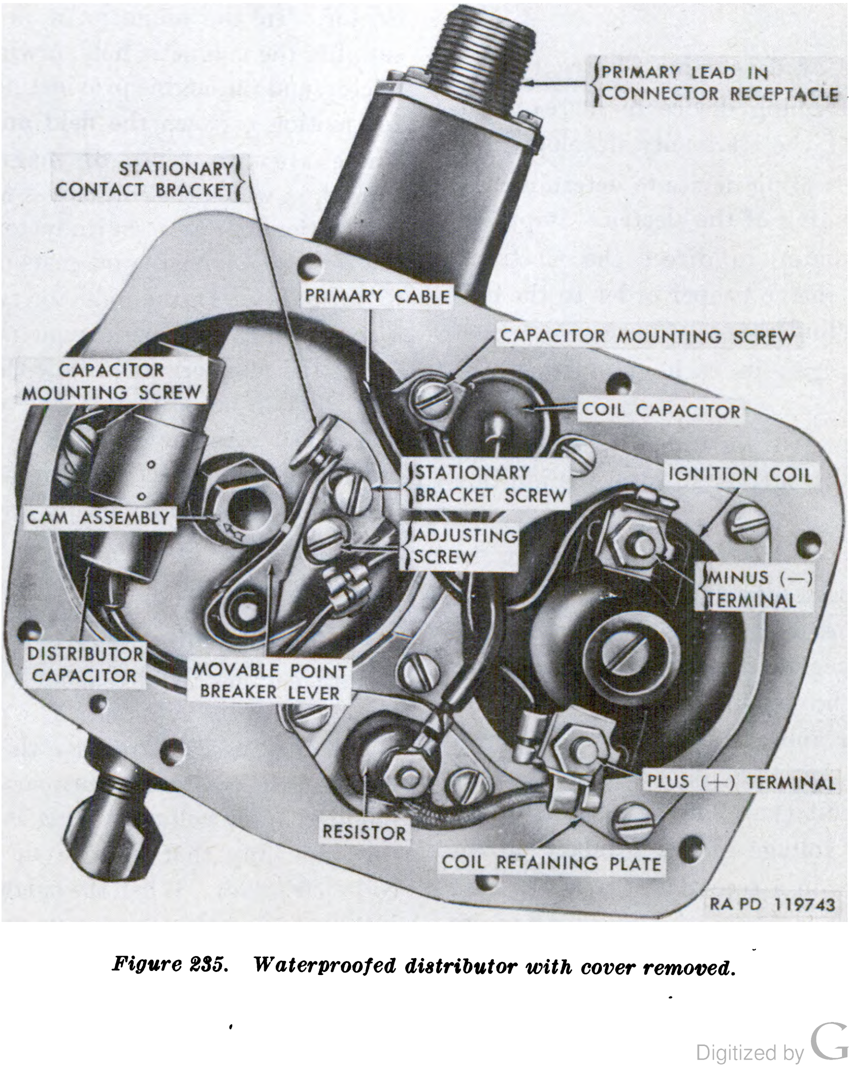

PRIMARY LEAD IN CONNECTOR RECEPTACLE
STATIONARY CONTACT BRACKET
PRIMARY CABLE
CAPACITOR MOUNTING SCREW
CAPACITOR MOUNTING SCREW
COIL CAPACITOR
STATIONARY BRACKET SCREW
IGNITION COIL
CAM ASSEMBLY
ADJUSTING SCREW
MINUS (—) TERMINAL
DISTRIBUTOR CAPACITOR
MOVABLE POINT BREAKER LEVER
PLUS (+) TERMINAL
RESISTOR
COIL RETAINING PLATE
RA PD 119743

Figure 235. Waterproofed distributor with cover removed.

151. General

a. Ignition of the fuel-air mixture in the combustion chamber of the gasoline engine requires an electric spark. The electric spark can be produced in two ways: by magneto ignition or by battery ignition. The magneto is a compact combination of generator, ignition coil, and distributor. It requires no battery. Voltage is induced within the magneto by relative movement between a coil and the poles of a permanent magnet. Most radial engines, and many other engines as well (the 12-cylinder V-type engine shown in figure 27, for example), use magneto ignition.

b. The problem in magneto ignition is to generate a spark of sufficient voltage to ignite the fuel-air mixture instantly and to synchronize the spark with the engine cycle so that maximum power will be realized from the combustion. The fundamental units are listed in (1) through (6) below:

(1) A means of developing electricity.

(2) A transforming device to increase the voltage of the electricity developed.

(3) An interrupting device to determine the proper timing of the electrical impulses.

(4) A distributor to direct the electrical impulses in the proper order to the different cylinders.

(5) A spark gap in each cylinder in the engine.

(6) The proper wiring and switches to bring these units together to form the ignition system.

c. The first four units are contained within the magneto. The spark plug supplies the fifth unit; wiring and switches make up the sixth unit. The same four fundamental units that make up the magneto also can be classified broadly as just two parts, a generator and a transformer. The generator provides a means of inducing low voltage in a primary circuit (par. 149); the transformer changes the low voltage of the primary circuit to the hot voltage in a secondary circuit so that an extremely high spark can be produced across the spark-plug gap.

152. Advantages and Disadvantages of Magneto Ignition

The magneto ignition system is generally reliable, requires little maintenance, and does not have a battery to run down or wear out. Its principal disadvantage is that it turns so slowly during the cranking of the engine that a hot spark is not produced. Therefore, a supplementary high-voltage source must be provided. This may be a booster magneto or a high-tension coil to which primary current is supplied by a battery. In some magnetos, an impulse starter is provided which produces high armature speeds at engine cranking speeds to provide a hot spark.

153. Source of Electrical Energy

In studying the magneto, it should be understood that three things are necessary to induce voltage: an electrical conductor, a magnetic field, and relative motion between the field and the conductor. In the magneto, a permanent magnet supplies the magnetic field, a wire coil is the conductor, and the engine provides mechanical energy for motion between the field and the conductor. There are two types of magnetos: armature-wound, in which the coil moves while the magnets are stationary; and the inductor type, in which the reverse is true, the magnets move and the coil is stationary. In the inductor type, for example, a rotor which is a permanent magnet is used to direct the magnetic field flow through the windings, first in one direction and then in the other (fig. 236). As the winding is stationary, it is easier to make connections from it. Either type of construction satisfies the first requirement of an electric ignition system, that is, a means of developing electrical energy.

154. Transforming Device

Most engines require about 15,000 volts at the spark gap in the cylinder. The problem when the magneto is used is to raise the low voltage induced in the conductor (primary winding) to the required high voltage. This is accomplished in the same way that it is in the battery ignition coil (par. 149*c*). When the current in the primary winding or conductor is at its maximum flow, the circuit is suddenly broken, collapsing the electro-

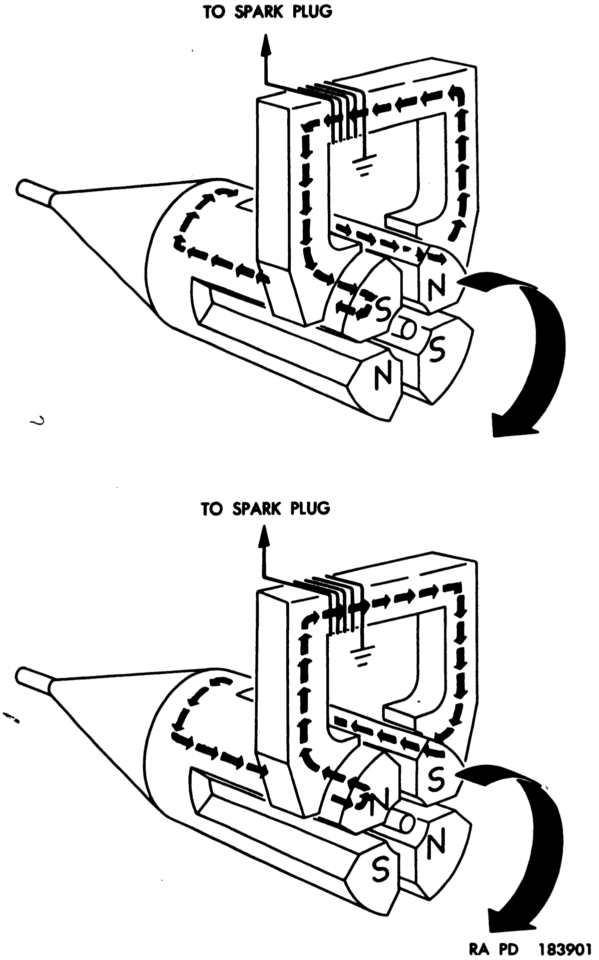


Figure 236. Two views of magneto rotor with magnetic field going through the winding, first in one direction and then in the opposite direction.

magnetic field set up around the primary circuit as the result of current flow. The lines of force in the field collapse at an extremely high rate of speed across the secondary winding, which is made up of many turns of fine wire, whereas the primary winding is composed of relatively few turns of coarser wire. This rapid movement of the lines of force across the secondary winding induces a momentarily high voltage in the secondary winding, in proportion to the ratio of the number of turns on the primary winding to the number on the secondary winding. This makes about 15,000 volts available at the spark gap.

155. Interrupting Device

a. Breaker Points. The interrupting device, which breaks the primary circuit when the high-voltage spark is desired, is a set of breaker points (fig. 237). One end of the primary winding is connected to ground; the other to the insulated breaker point. When the points are closed, the circuit is completed through them to a ground; when open, the circuit is broken. Lobes on a cam actuate the breaker points, interrupting the primary circuit and timing the induction of maximum voltage in the secondary circuit. The cam is mounted on either the armature or rotating magnet.

b. Capacitor. When the breaker points are opened, the current then flowing in the primary circuit, due to self induction, tends to arc across the points, reducing the speed with which the circuit is broken and the magnetic field collapsed. This action is controlled by inserting a capacitor in parallel with the breaker points. When the primary circuit is broken, the capacitor receives the surge of current and then, on discharging, reverses the normal flow of current; it thus hastens the collapse of the magnetic field around the primary winding and increases the amount of voltage

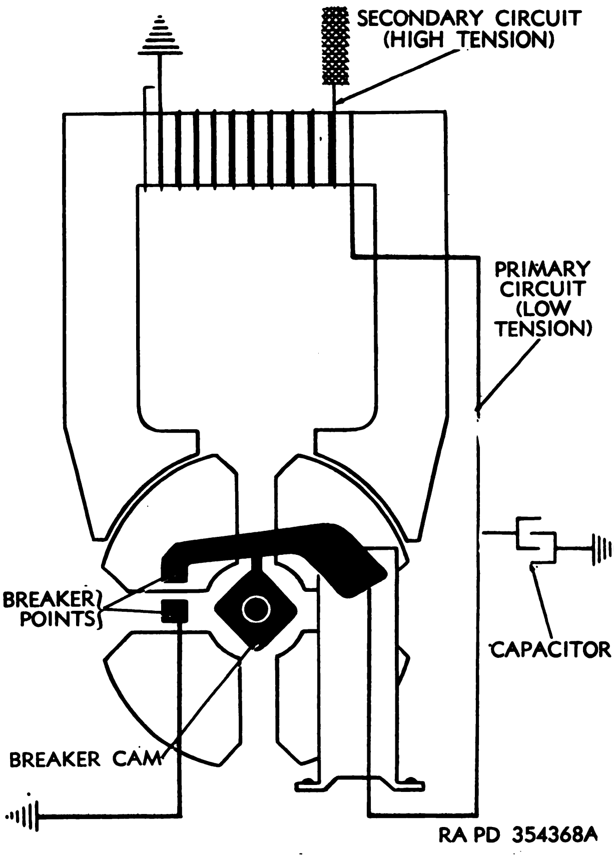

SECONDARY CIRCUIT (HIGH TENSION)
PRIMARY CIRCUIT (LOW TENSION)
CAPACITOR
BREAKER POINTS
BREAKER CAM
RA PD 354368A

Figure 237. Magneto rotor and winding, with transforming and interrupting devices added.

induced. Refer to paragraph 147 for more details on capacitor action.

156. Distributor

a. The distributor rotor, which directs the electrical impulses in proper order to the cylinders, is usually driven through suitable gearing, at one-half crankshaft speed. This ratio insures that each cylinder will be fired during the cycles of the engine. Figure 238 shows the location of a rotor, cam, and breaker assembly in a late-model magneto. The cam is much larger than those used in battery ignition distributors and contains the contact spring and cam electrode which, together, serve the same purpose as the rotor segment in a battery ignition distributor. That is, the cam electrode connects the high-tension center electrode (connected to secondary of coil) to each of the outer distributor electrodes in turn. These outer electrodes are connected by high-tension leads to the spark plugs.

b. One end of the secondary winding is connected to the primary. The other end terminates at the high-tension insert, which is a piece of metal extending through the Bakelite case covering the coil. The high-tension voltage developed in the secondary coil passes through the insert to a contactor such as the high-tension contact spring shown in the magneto cover in figure 238. From there, it goes to the center electrode and then, internally, through the distributor rotor to the outer electrodes. The rotor is timed so that the cam electrode will line up with the center electrodes to which spark plug leads are connected, at the proper time for igniting the fuel-air charges in the cylinders.

c. The spark plug assembly provides a gap where a surge of high voltage may cause a spark

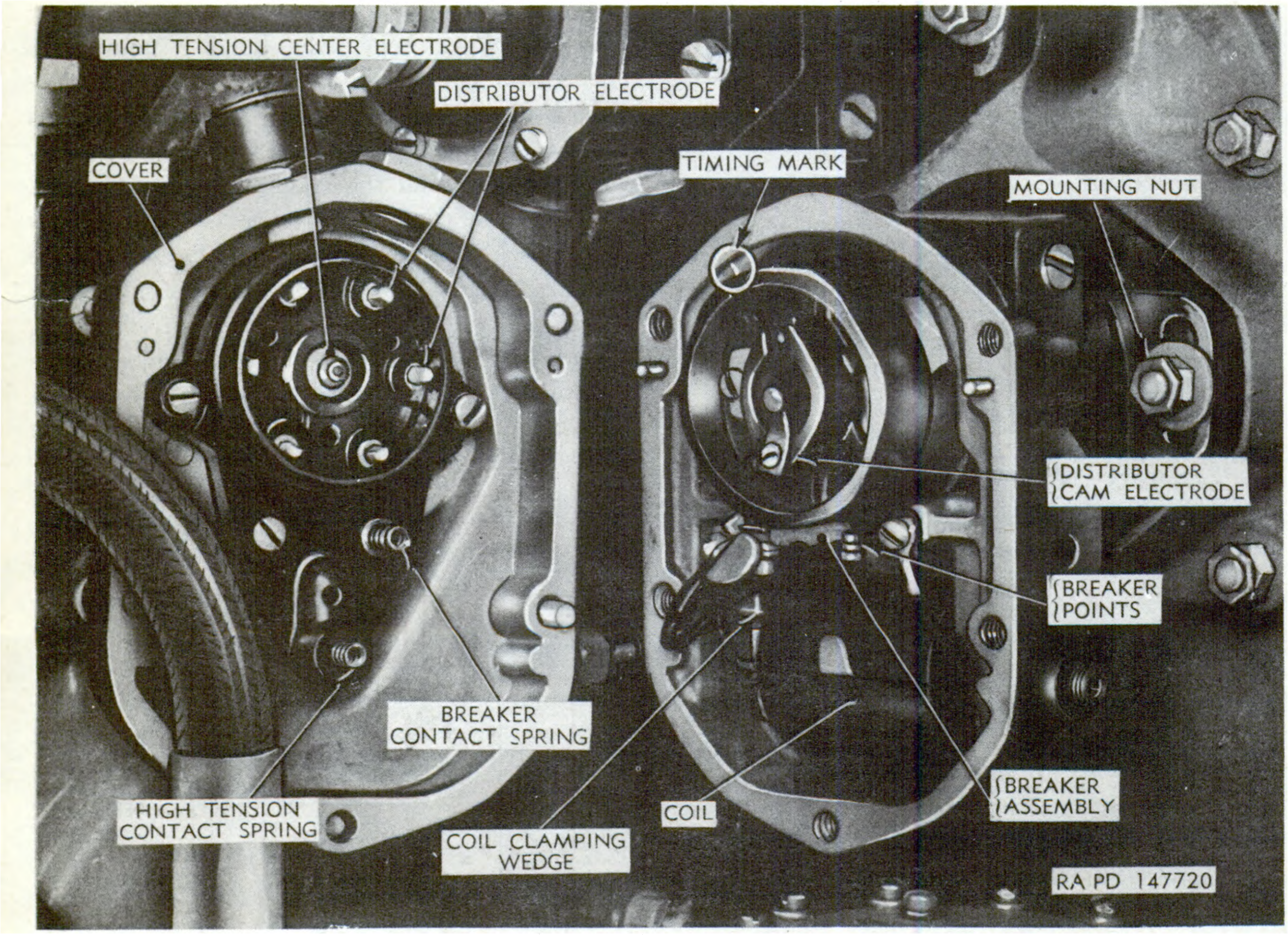

HIGH TENSION CENTER ELECTRODE
DISTRIBUTOR ELECTRODE
COVER
TIMING MARK
MOUNTING NUT
DISTRIBUTOR CAM ELECTRODE
BREAKER POINTS
BREAKER CONTACT SPRING
BREAKER ASSEMBLY
HIGH TENSION CONTACT SPRING
COIL
COIL CLAMPING WEDGE
RA PD 147720

Figure 238. Magneto with cover removed.

to ignite the fuel-air mixture. One spark plug electrode is connected to the high-tension cables from the distributor blocks; the other is fastened to a ground. Most air cooled engines have two spark plugs for each cylinder and two separate magnetos for the ignition system. The second spark plug insures better combustion and is added insurance against ignition failure.

d. The high-tension wires which conduct the current from the distributor blocks to the spark plugs are commonly called the *ignition harness.* As a magneto ignition system transmits a form of high-frequency current, radiations emanating from it during operation will interfere with radio reception if the ignition system is not shielded. This shielding is a metal covering of woven construction that surrounds the wires. Plain metallic shields cover the distributor blocks and booster coil. The shielding is grounded to the engine so that it can pick up the undesirable radiations from the magneto and carry them directly to a ground. The rediations are thus prevented from reaching the vehicle's radio aerial and interfering with reception.

157. Booster Coil

Magneto speed during cranking is not high enough to develop a hot spark (par. 152). An external source of high-tension current for starting is provided, either by a booster magneto or by a high-tension coil, with the primary current being supplied by a battery. The coil method is most common. Current from the booster coil, which operates just like the coil in the battery ignition system, is conducted to the booster electrode of the magneto. This connects the booster coil with the magneto primary coil when the contacts open, thereby causing a current surge through the primary (from the booster coil) which produces a rapid change of magnetic field strength in the primary. This action induces in the secondary a high-voltage surge sufficiently strong to fire the plugs.

158. Magneto Switches

a. Since the magneto is self-energizing, it cannot be turned off by disconnecting it from some external source of energy as in the battery ignition system. Instead, the magneto coil must be grounded. Since one end of the magneto coil is already grounded, grounding the other (or breaker point) end will effectively prevent the magneto from producing high-voltage surges. This is accomplished by means of a grounding switch on the vehicle instrument panel. When the switch is turned off, contacts in the switch are closed and the magneto coil is grounded through them. Figure 239 illustrates an instrument panel on a combat vehicle. The magneto, booster, and main-engine starter switches are all located together in the same housing. The main magneto switch actually has four positions since, in the application shown, four magnetos are used (par. 159). The four positions are OFF (all magnetos grounded), "A" (two of the magnetos which fire the plugs in the accessory ends of cylinders are ungrounded and operative), "F" (the two magnetos which fire the plugs in the flywheel ends of the cylinders are ungrounded and operative), and "BOTH" (all four magnetoes are operative).

b. The magneto switch is mounted in the same housing with the booster and the main-engine starter switch (fig. 239). This places the switches, that must be operated for starting together. The starter switch, when operated, closes a relay which, in turn, brings the starter into operation. At the same time that the starter switch is operated, the booster switch also must be operated. This switch, just next to the starter switch, connects the booster coil into the circuit when closed. Both the starter switch and the booster switch are spring-loaded and so placed that their levers must be brought down and pivoted toward each other for closing. Thus, both can be closed by the thumb and fingers of one hand. If the magneto switch has been turned to "BOTH" meantime, the starter will crank the engine while the booster coil will aid the magnetos to produce ignition. The combination then produces starting, provided other conditions are normal. When the starter-switch and booster-switch levers are released, they return automatically to their OFF positions.

159. A Typical 4-Magneto, 12-Cylinder Ignition System

a. In figure 240, the wiring diagram of a 4-magneto, 12-cylinder ignition system is shown. A careful study of this system should be made since it embodies various features. Each cylinder has two spark plugs. The plug toward the flywheel

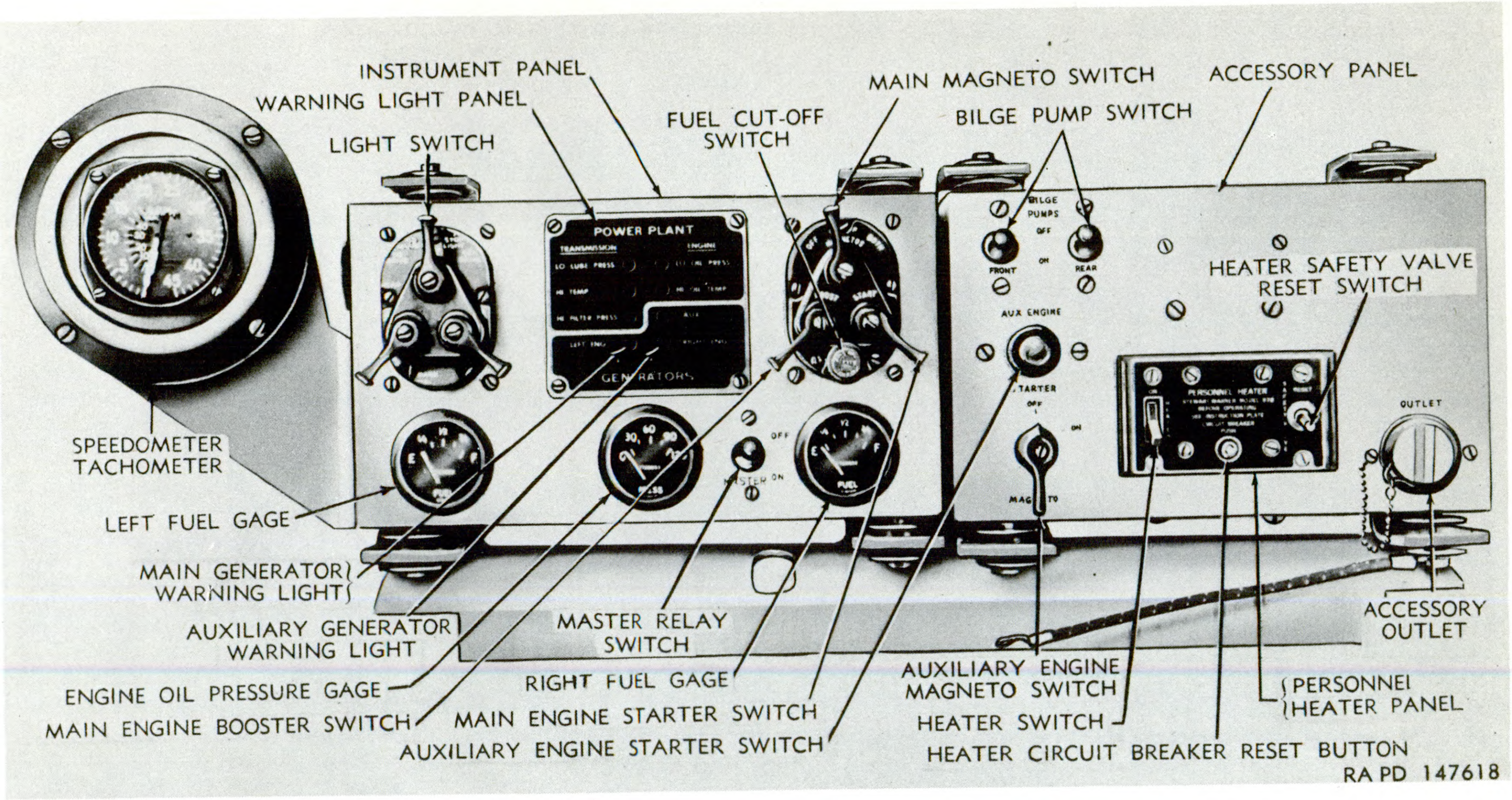

INSTRUMENT PANEL
WARNING LIGHT PANEL
LIGHT SWITCH
FUEL CUT-OFF SWITCH
MAIN MAGNETO SWITCH
BILGE PUMP SWITCH
ACCESSORY PANEL
HEATER SAFETY VALVE RESET SWITCH
SPEEDOMETER TACHOMETER
LEFT FUEL GAGE
MAIN GENERATOR WARNING LIGHT
AUXILIARY GENERATOR WARNING LIGHT
ENGINE OIL PRESSURE GAGE
MAIN ENGINE BOOSTER SWITCH
MASTER RELAY SWITCH
RIGHT FUEL GAGE
MAIN ENGINE STARTER SWITCH
AUXILIARY ENGINE STARTER SWITCH
AUXILIARY ENGINE MAGNETO SWITCH
HEATER SWITCH
HEATER CIRCUIT BREAKER RESET BUTTON
PERSONNEL HEATER PANEL
ACCESSORY OUTLET
POWER PLANT
GENERATORS
BILGE PUMPS
OFF
ON
FRONT
REAR
AUX ENGINE
STARTER
MAG TO
MASTER
FUEL
OUTLET
PERSONNEL HEATER
RA PD 147618

Figure 239. Instrument and hull accessory panels.

end of the engine is designated as an "F" plug. The plug toward the accessory end of the engine is designated as an "A" plug. Each magneto fires six plugs. The two lower magnetos fire the "F" plugs while the two upper magnetos fire the "A" plugs. This arrangement provides, in effect, two independent ignition systems. The engine can run on one of these systems and the magneto switch has "A" and "F" positions, whereby either the two upper or the two lower magnetos can be made operative. These positions can be used for checking one or the other of the systems for maintenance or adjustment purposes. For normal operation, the magneto switch will be turned to "BOTH" so that all four magnetos are operative.

b. The engine on which the 4-magneto ignition system is used is a V–12 engine. The upper left and lower left magnetos fire the plugs in the left bank of cylinders, while the upper right and lower right magnetos fire the right bank of cylinders. The two left magnetos must be closely synchronized with each other, just as the two right magnetos must be synchronized. Synchronization is important here because the magnetos are to fire, simultaneously, the two plugs in a cylinder. Since each magneto fires one plug in each cylinder, the two magnetos must work at the same instant.

c. The magnetos are weatherproof; that is, they are sealed units provided with a breather system from the engine. There is an intake from the air cleaner and an outlet to the engine intake manifold. The manifold vacuum therefore draws air through the magnetos and prevents condensation of moisture. In addition, they are shielded to prevent electromagnetic radiations which could interfere with radio operation or cause detection of the vehicle by enemy forces using radio detection devices.

d. Two wiring harnesses are provided, one for each bank. Each harness has 12 high-tension cables inclosed in a conduit. The shielding conduit over the spark plug end of the cable is furnished with a nut and ferrule which assures a tight connection and firm fastening of the conduit to the plug.

e. The filter coils, which are mounted together in the same cases with the booster coils, have the purpose of acting as radio interference suppressors, bypassing to ground any radio interference signal from the ignition system.

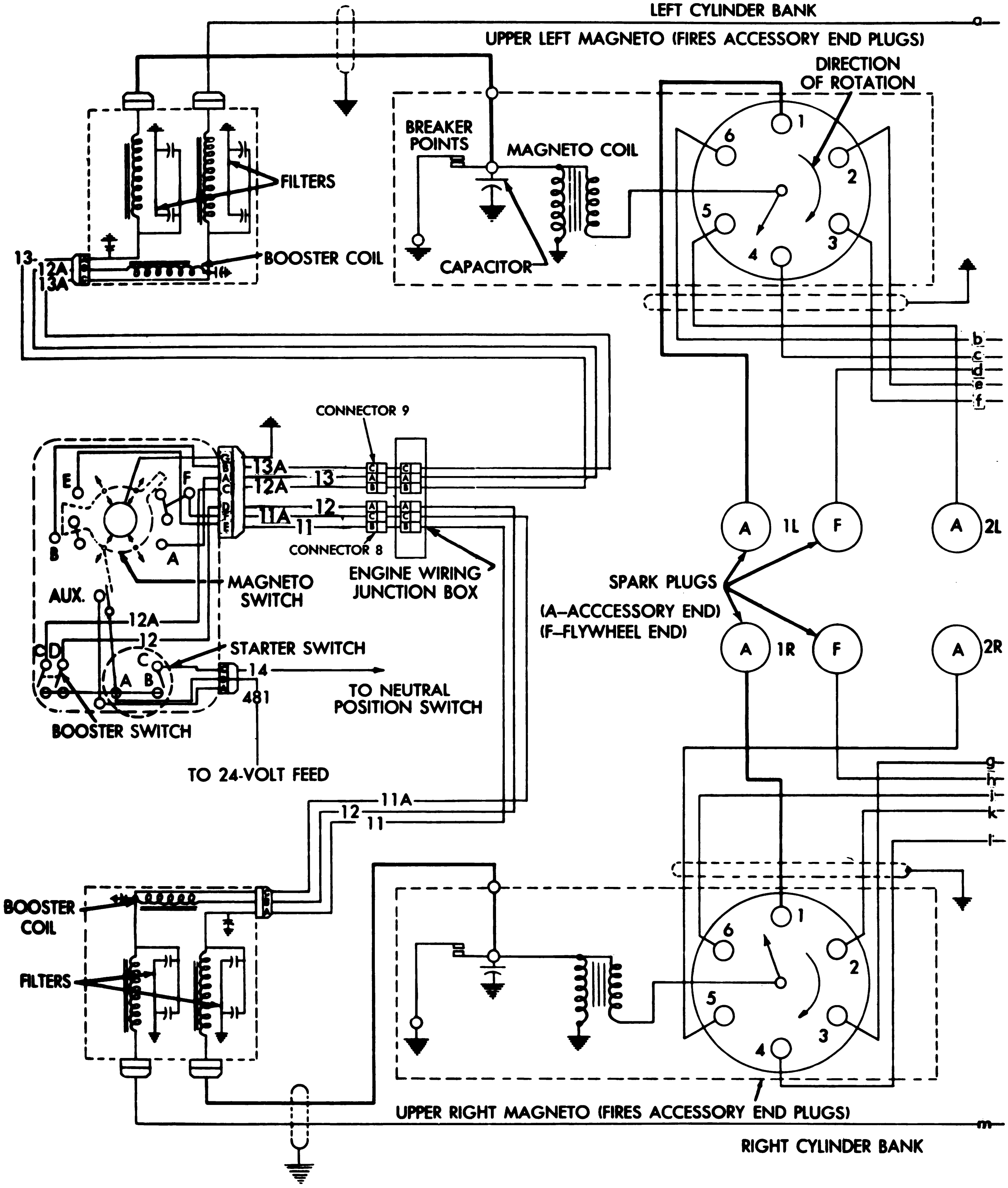

LEFT CYLINDER BANK
a
UPPER LEFT MAGNETO (FIRES ACCESSORY END PLUGS)
DIRECTION OF ROTATION
BREAKER POINTS
MAGNETO COIL
FILTERS
BOOSTER COIL
CAPACITOR
13
12A
13A
1
2
3
4
5
6
b
c
d
e
f
CONNECTOR 9
CONNECTOR 8
G
B
A
C
D
F
E
13A
12A
11A
13
12
11
E
F
B
A
MAGNETO SWITCH
ENGINE WIRING JUNCTION BOX
AUX.
12A
12
C
D
A
B
STARTER SWITCH
14
481
TO NEUTRAL POSITION SWITCH
BOOSTER SWITCH
TO 24-VOLT FEED
A
1L
F
A
2L
SPARK PLUGS
(A–ACCCESSORY END)
(F–FLYWHEEL END)
A
1R
F
A
2R
g
h
j
k
l
11A
12
11
BOOSTER COIL
FILTERS
UPPER RIGHT MAGNETO (FIRES ACCESSORY END PLUGS)
m
RIGHT CYLINDER BANK

Figure 240. Wiring diagram of a 4-magneto ignition system.

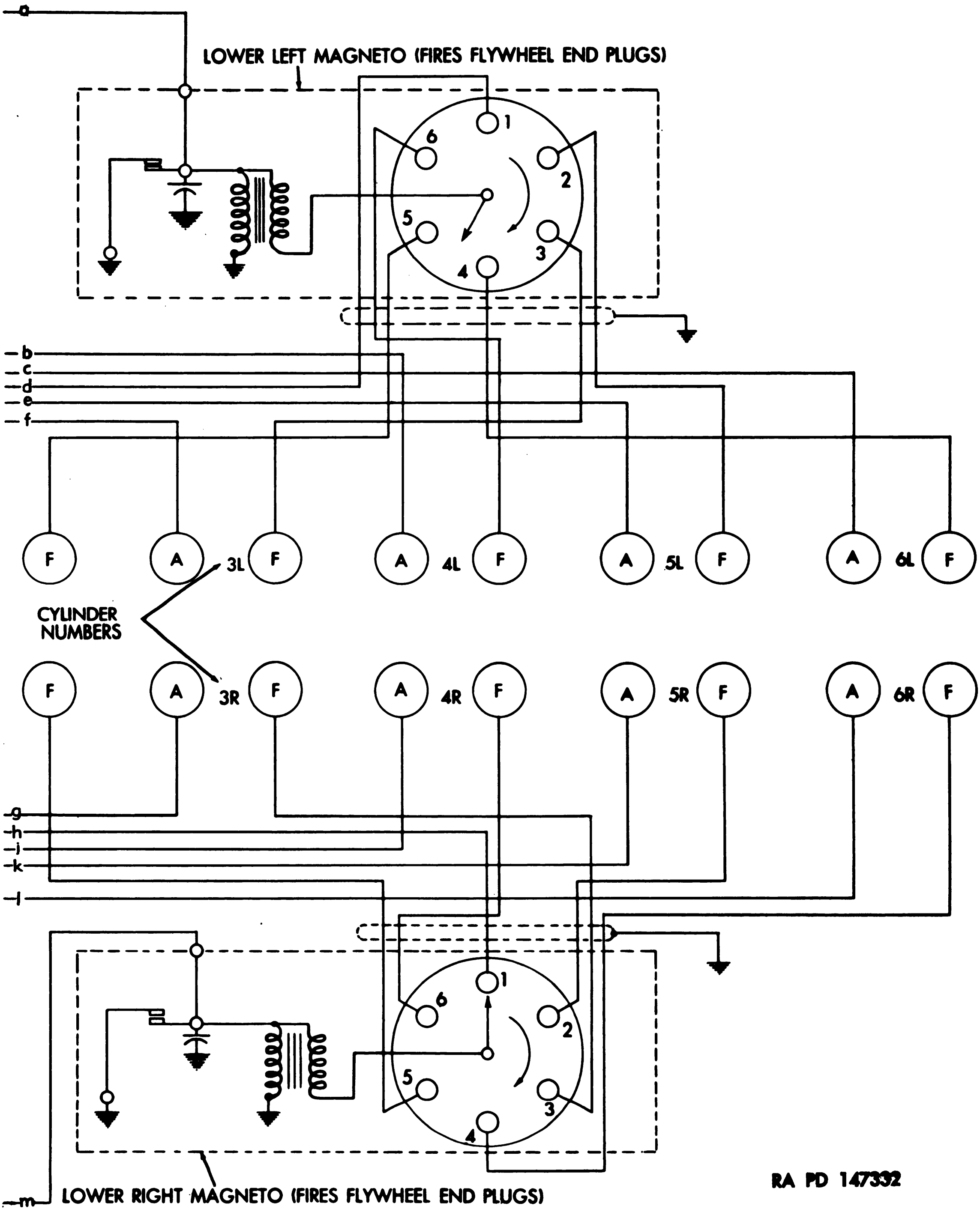

a
LOWER LEFT MAGNETO (FIRES FLYWHEEL END PLUGS)
1
2
3
4
5
6
b
c
d
e
f
F
A
3L
F
A
4L
F
A
5L
F
A
6L
F
CYLINDER NUMBERS
F
A
3R
F
A
4R
F
A
5R
F
A
6R
F
g
h
j
k
l
1
2
3
4
5
6
m
LOWER RIGHT MAGNETO (FIRES FLYWHEEL END PLUGS)
RA PD 147332

Figure 240. Wiring diagram of a 4-magneto ignition system—Continued

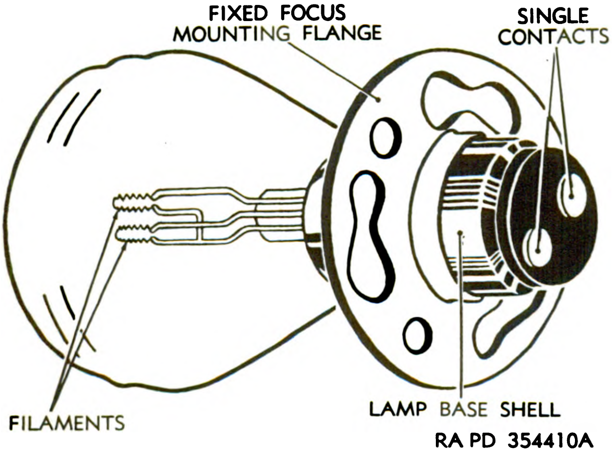


Figure 241. Double-filament headlight lamp.

160. Motor Vehicle Lighting

The history of motor vehicle lighting parallels the history of the lighting of houses and buildings, oil lamps and gas lamps having been used in the early motor vehicles. With the development of a satisfactory electrical system, electric lighting has become the standard means of lighting motor vehicles. The lighting system as found on most modern motor vehicles consists of the following:

a. Two headlights for illuminating the road ahead of the vehicle.

b. Two parking, or side, lights for indicating primarily the location of the vehicle when parked.

c. Taillights to illuminate the rear license number plate and to show a red light to the rear.

d. Instrument panel lights to illuminate the instruments.

e. Body lights, such as dome and step lights, to light the interior of the vehicle.

f. Special lights, such as spotlights, signal lights, blackout lights, and stop and backing lights.

g. Wires and control switches to connect these lights and lamps to the current source.

161. Lamps

a. General. Small gas-filled incandescent lamps with tungsten filaments are used on motor vehicles. The filaments supply the light when sufficient current is flowing through them. The lamps are designed to operate at low voltage, that is 6, 12, or 24 volts (corresponding to the voltage of the electrical system used), and are wired to operate from control switches located within convenient reach of the driver.

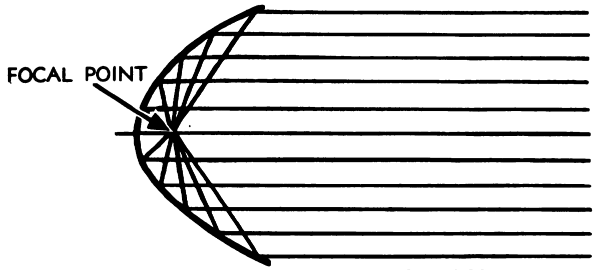
b. Construction. Most lamps are provided with a single contact for each filament within the lamp, the current through each filament being completed to the shell of the lamp base. A double filament lamp with the single-contact construction is shown in figure 241. Two contacts are provided on the lamp base, each being connected with one of the filaments. The return from both filaments is to the lamp base shell which is grounded through the lamp socket. Thus, there are two separate circuits with two contacts on the base, each of which might properly be termed a single contact, for a grounded circuit.

c. Size. Lamps range in size from the small ½-candlepower instrument panel lamps to the large 50 or more candlepower driving lamps. Inasmuch as the voltage used is low and the current required as a result is high, the filaments are much shorter and stronger than those used for standard house lighting lamps. A short and thick, rather than a long and thin, filament naturally stands more rough treatment, and this is desirable in the case of a lamp subjected to the vibrations of a motor vehicle. A short filament also provides a concentrated light source that will give a better focus. The 2-candlepower lamp consumes 0.43 amp at 6 volts. The 4-candlepower lamp consumes 0.85 amp at 6 volts. A lamp similar to the one shown in figure 241, having two filaments, one of 32 candlepower and the other of 21 candlepower, will draw 3.9 and 2.8 amps.

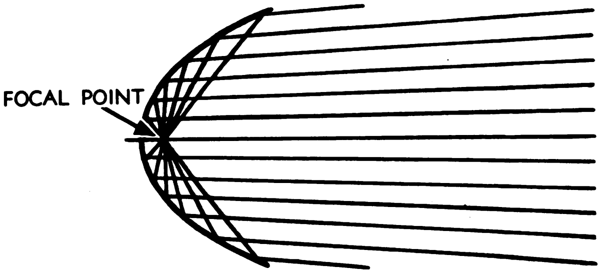
d. Current Requirements. One reason for the rapid discharge of storage batteries in winter is the increased number of hours which lamps are used. Naturally, there is a direct relation between the total current consumption and the number of lamps used. All storage batteries are rated by ampere-hours; that is, the number of hours a battery can be used at a certain discharge amperage before it becomes depleted. For instance, two headlight lamps burning at 4 amps each, a total of 8 amps, would discharge a storage battery rated at 80 ampere-hours in approximately 10 hours, unless the generator charged the battery.

162. Light Beams

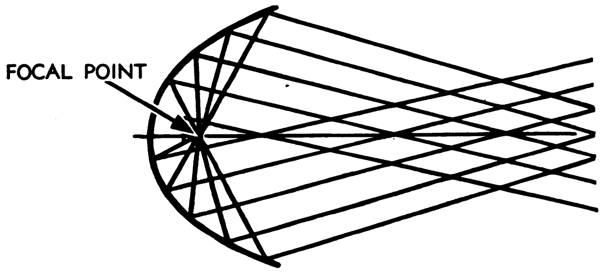
a. Use of Reflector. A lamp bulb is mounted within a reflector so that the light can be gathered and directed in a confined beam. The best light beam from a lamp is obtained by the use of a para-



1—LAMP AT FOCAL POINT



2—LAMP BEHIND FOCAL POINT



3—LAMP AHEAD OF FOCAL POINT

RA PD 354411A

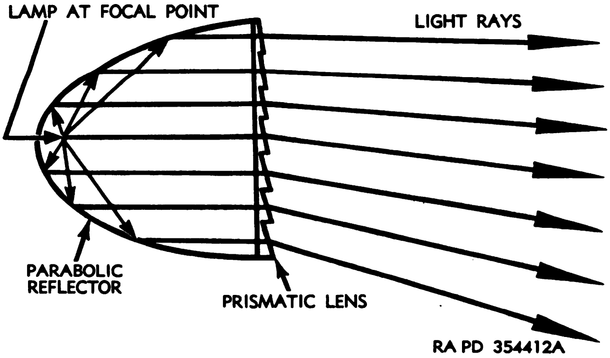
Figure 242. Effect of lamp position in parabolic reflector.

bolic reflector, which is the type in general use. There is a focal point near the rear of the parabolic reflector at which the light rays from the lamp are picked up by the polished surface of the reflector and directed in parallel lines to give a beam with a circular cross section. Any other position of the lamp will not give as confined a beam, but will tend to scatter the light (fig. 242).

b. Use of Prismatic Lens. The light beam is distributed over the road by means of a prismatic lens. The effect of a prismatic lens fitted to parabolic reflector is shown in figure 243. The lens bends the paralled rays from the reflector so that the light is distributed over the road. The vertical flutes of the lens spread the light rays so that the beam is flattened, with the edges thrown out toward the side of the highway.

c. Plastic Lamp Lens. On late-model water-fording vehicles equipped with 24-volt electrical systems, plastic lenses are used. The plastic lens looks and feels like glass, but is more resistant to breakage from variations in temperature and water pressure. However, the plastic lens must have special treatment or it will deteriorate. Molded plastic has a surface tension, and anything that attacks the surface releases the tension so that "crazing," or "checking," takes place. Further deterioration may follow with the plastic softening, warping, and fogging. All this reduces the amount of light that can get through and lowers the efficiency of the lights. For this reason, plastic lenses must not be cleaned with strong cleaners, solvents, thinners, scouring compounds, or even with cloths that have any trace of dust or dirt in them. Clean water and soap is the best cleaner for plastic lenses. They should not be rubbed with a dry cloth as this will build up static electricity and attract dust, so that further rubbing will scratch the lens.

d. Combinations of Beams. Many combinations of light beams are possible. One combination of headlight beams that has been commonly used is shown in figure 244. The beam from the right headlight (A, fig. 244) is projected high to the right side of the road and low to the left side, and the beam from the left headlight (B, fig. 244) is projected high to the left side and low to the right side. Portions of the beam are deflected lower than other portions because of the design of the lens. When the right and left beams are not the same (A and B, fig. 244), the lenses for right and left headlights are not interchangeable. These beams combine to give a nearly symmetrical beam for driving (C, fig. 244). With some headlights, the left light illuminates the right side of the road, while the right light illuminates the left side of the road. Both lights together give a symmetrical beam somewhat similar to that in C of figure 244. The present tendency is toward a



RA PD 354412A

Figure 243. Rays of light from headlight, distributed by prismatic lens.

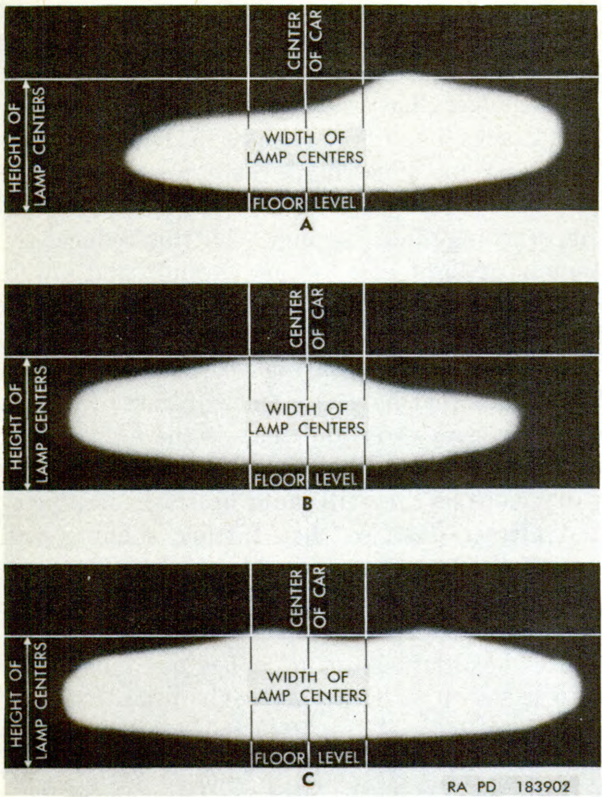

CENTER OF CAR
HEIGHT OF LAMP CENTERS
WIDTH OF LAMP CENTERS
FLOOR LEVEL
A
CENTER OF CAR
HEIGHT OF LAMP CENTERS
WIDTH OF LAMP CENTERS
FLOOR LEVEL
B
CENTER OF CAR
HEIGHT OF LAMP CENTERS
WIDTH OF LAMP CENTERS
FLOOR LEVEL
C
RA PD 183902

Figure 244. Headlight beams.

spreading beam which illumines a wide area rather than a concentration of the beam directly in front of each headlight.

163. Headlights

a. General.

(1) In headlights of the older type, means are provided for focusing and directing the light. By *focusing* is meant bringing the filament of the lamp to the focal point of the reflector; by *aiming* is meant pointing or directing the light properly.

(2) Later developments brought into general use a 2-filament lamp having its position fixed with respect to its mounting socket at the rear of the reflector so that the filaments remain fixed at the proper focus (fig. 242). To improve the lighting of the roadway it is necessary only to direct the light.

b. Parts. The principal parts of an automobile headlight are the housing, with some means provided for mounting the housing; headlamp (bulb) and socket; reflector; and lens with rim and gasket to hold the lens in place and to keep dust out of the headlight interior. These parts are shown in figure 245. One of the lamp filaments, a larger filament, is placed close to the focal point to obtain a good beam for driving on the highway, while a second filament is placed just off the focal point so that a depressed beam is obtained for passing other cars and for city driving. A parking lamp is at times also incorporated within the headlight. Figure 246 illustrates the construction of a headlight assembly using a sealed beam unit (par. *c*).

c. Sealed Beam.

(1) A superior headlight that has been adopted is the sealed-beam headlamp unit. Not only does it provide far better and more powerful illumination than previous lamps, but it maintains its initial brilliancy with only a slight loss throughout its life. This is because the lens is permanently sealed to the reflector, effectively barring moisture (which corrodes the reflector) and preventing the entrance of dust and dirt.

(2) When a filament burns out, the whole unit must be replaced. However, it has a greater filament life than other types of lamps and requires no maintenance to keep it in good condition.

(3) The sealed-beam headlamp unit is made in two types; one with a silver-plated metal reflector and the other with an aluminum-surfaced glass reflector. The metal type contains a conventional double-filament lamp which is mechanically sealed in the unit, whereas the glass type is its own lamp since the lens and reflector are fused together, forming a gastight unit with the filaments sealed into the reflector (fig. 247).

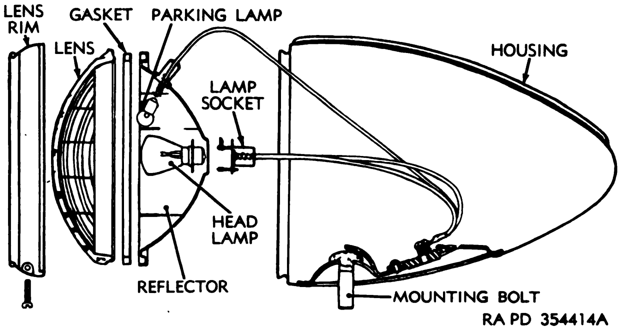

LENS RIM
GASKET
PARKING LAMP
LENS
HOUSING
LAMP SOCKET
HEAD LAMP
REFLECTOR
MOUNTING BOLT
RA PD 354414A

Figure 245. Headlight construction.

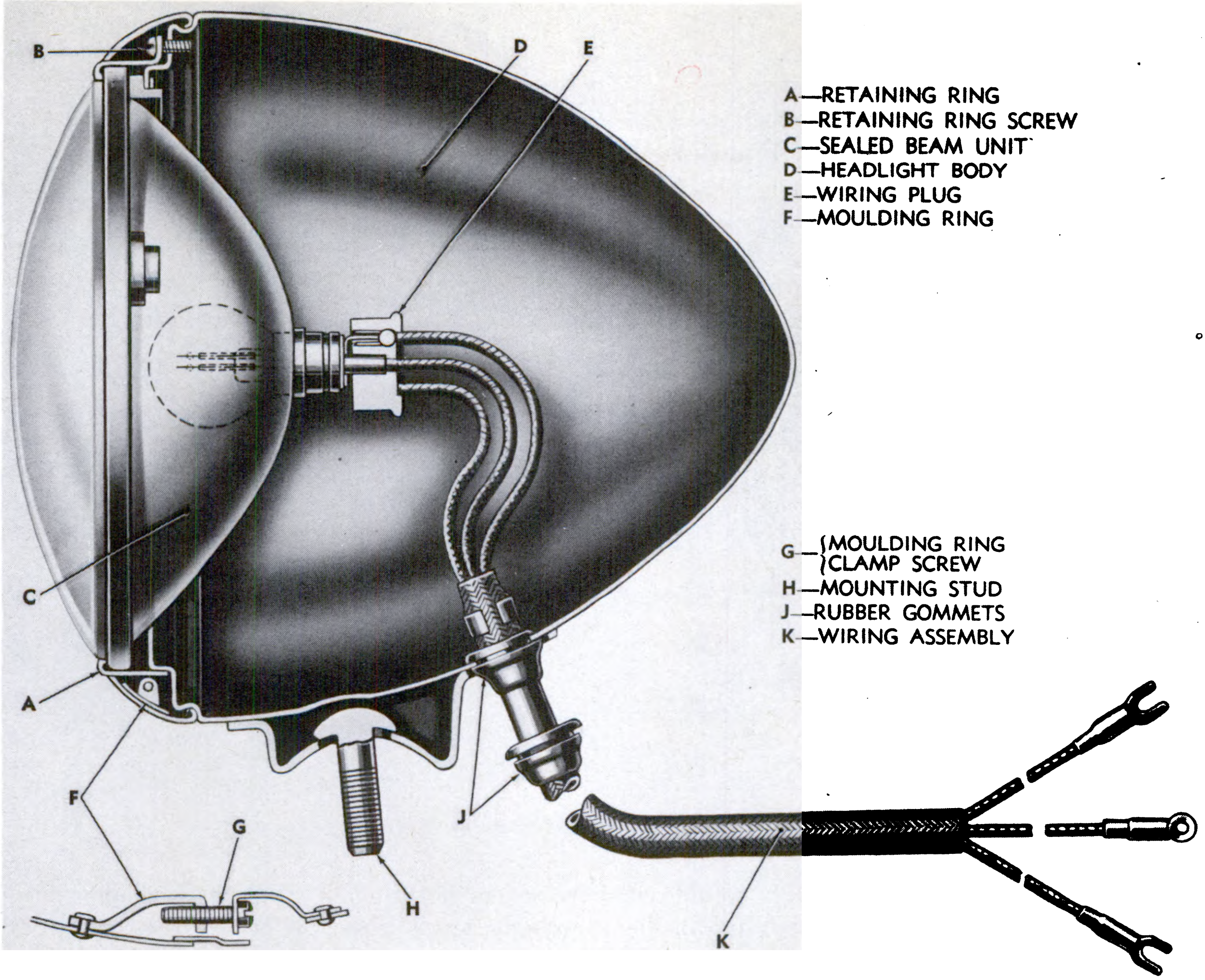

A—RETAINING RING
B—RETAINING RING SCREW
C—SEALED BEAM UNIT
D—HEADLIGHT BODY
E—WIRING PLUG
F—MOULDING RING
G—{MOULDING RING CLAMP SCREW}
H—MOUNTING STUD
J—RUBBER GOMMETS
K—WIRING ASSEMBLY
A
B
C
D
E
F
G
H
J
K
RA PD 64765A

Figure 246. Headlight assembly.

(4) Two filaments are provided in the sealed-beam headlight lamp unit; one furnishing an upper beam for country driving, and the other giving a depressed beam for passing or city driving. With the upper beam in use, the new sealed-beam lamp units provide 50 percent more light than previous 32-candlepower lamps, and also distributes the light more effectively. The upper beam filament requires 40 to 45 watts, and the depressed beam filament requires 30 to 35 watts, which is more current than that required by the 32-candlepower lamps. Directing the headlight to the roadway is the only adjustment required on sealed-beam headlamps. Parking lights are separate.

d. Mounting. The two headlights are mounted so that their centers are between 32 and 42 inches from the ground. The lights are supported by brackets from either the fender or chassis frame, or both, and are usually sufficiently adjustable to permit changes in the vertical and the horizontal angle of the headlights to aim the beam correctly.

164. Elimination of Glare

a. Cause of Glare. Any light source is said to produce glare if it appreciably reduces the distinctness of vision of anyone looking toward it. Practically speaking, the blinding or dazzling effect of light is not due so much to the brilliancy of the light as to the lack of illumination in the immediate vicinity through which the rays are projected. The headlight, for example, which

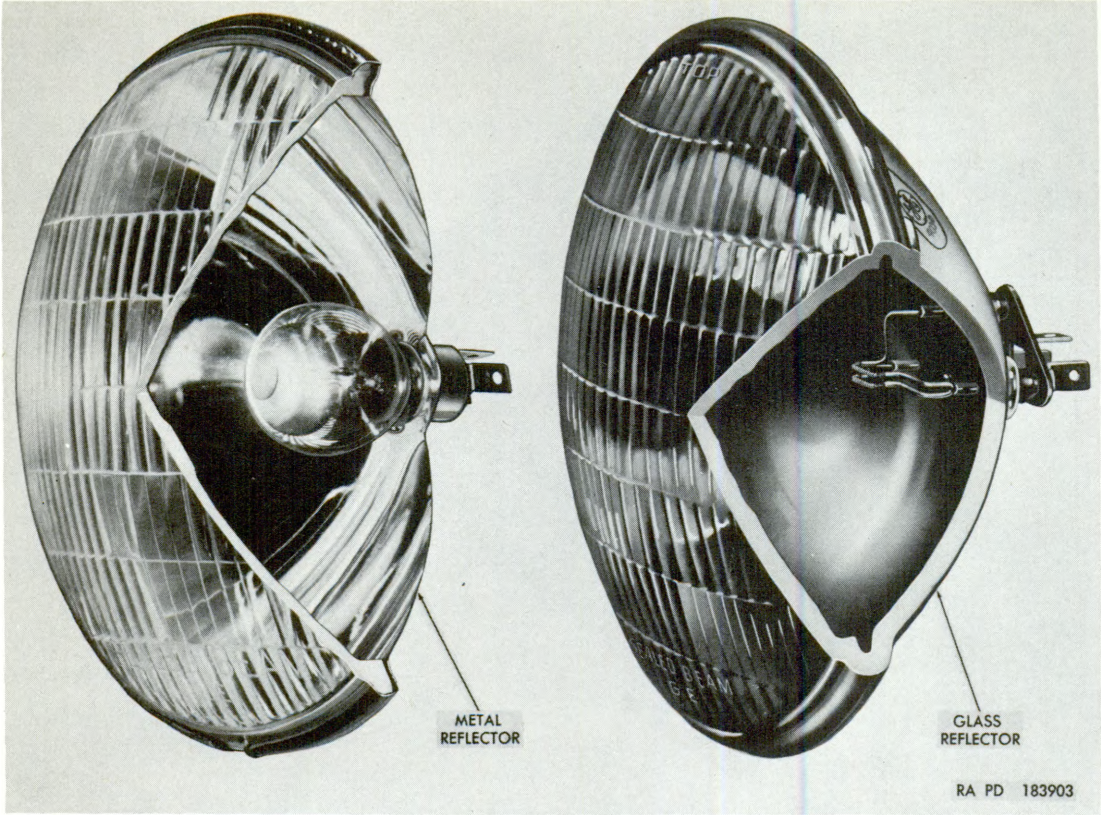


Figure 247. Sealed beam headlight lamp units—sectional views.

produces glare on a dark road at night would not produce glare on a well-lighted street, and in the daytime with the sun shining, it would hardly be noticed. If the strong light rays can be kept below the eye level, the nuisance of glare will be largely eliminated.

b. Elimination. Many tests have been conducted by the Society of Automotive Engineers and by manufacturers to eliminate headlight glare as much as possible and still have sufficient illumination for safe driving. Two beams are specified to meet these requirements; an upper beam to provide sufficient illumination in front of the vehicle while driving, and a depressed beam to avoid dangerous glare under normal conditions of passing. The driver is responsible for selecting the proper beam. The maximum and minimum intensity at important points of both beams are definitely specified and can be checked with the light intensity or foot-candle meter.

165. Road Illumination

Until recently, many of the States had laws prohibiting the use of lamps of over 32 candlepower in headlights. Modern development has brought about a radical change in what is considered good road illumination. The high-intensity beam of light has given way to the principle of more illumination and lower general intensity. The 32-candlepower lamp is sufficient with a narrow, high-intensity beam, but with the general floodlighting effect desired today, a larger light source is necessary. The sealed-beam headlamp has been developed to meet these requirements. With the increased use of high-powered lamps have come laws enforcing the proper focusing of the lights and the use of dual-beam headlamps.

166. Adjusting Headlights

a. Earlier types of headlights require both focusing and directing adjustments, and it is necessary to first check the focusing of the headlights before adjusting them for aim (that is, shifting the beam up or down, right or left). The vehicle should be placed in front of a screen (fig. 248), and adjustment of the focus made by the means provided. A common arrangement is to turn an adjusting screw at the rear of the headlight, which

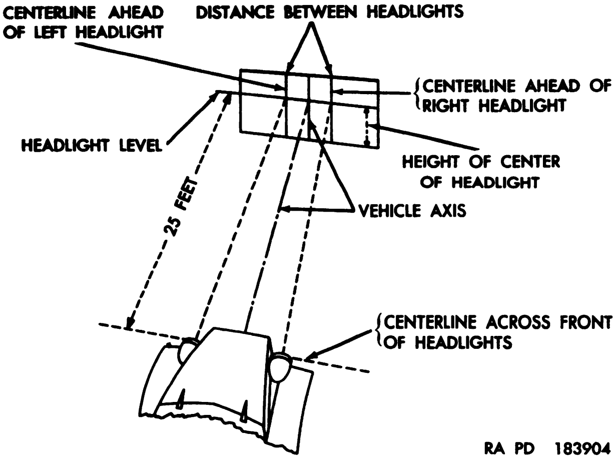

CENTERLINE AHEAD OF LEFT HEADLIGHT
DISTANCE BETWEEN HEADLIGHTS
CENTERLINE AHEAD OF RIGHT HEADLIGHT
HEADLIGHT LEVEL
HEIGHT OF CENTER OF HEADLIGHT
25 FEET
VEHICLE AXIS
CENTERLINE ACROSS FRONT OF HEADLIGHTS
RA PD 183904

Figure 248. Headlight adjustment chart.

moves the bulb forward or backward. Adjustment is best when the most concentrated light is obtained on the screen.

b. Since most later type headlights are fixed-focus, only the aiming of the headlights requires adjustment. For aiming, the vehicle should be positioned as shown in figure 248, 25 feet from a smooth vertical surface that can serve as a screen (if a screen is not available). The center line of the vehicle should be at right angles to the vertical surface.

c. Measure the height of the headlight center from the floor, and then draw a horizontal line on the vertifical surface at this height. Locate the point on this line at which the projected center line of the vehicle intersects it. Measure the distance between the headlight centers and divide this distance equally on both sides of the center point. Draw vertical lines through each of these points (fig. 248). The points represent the centers of the right and left headlights.

d. To check the headlight aiming, turn on the headlights and select the upper, or high, beam with the selector switch. Cover one headlight while adjusting the other. Loosen nut attaching headlight to bracket on the fender. On other types which are recessed, adjustment is made by turning horizontal and vertical aiming screws. Aim the headlight in the manner shown in figure 249 and tighten adjustment, taking care not to change the location of the light-beam pattern on the screen. Cover the light that has been adjusted and adjust the other headlight in the same manner.

167. Depressed Beam

Double-filament lamps are commonly used at the present time to obtain both driving beams from one lamp. The lamp is designed so that

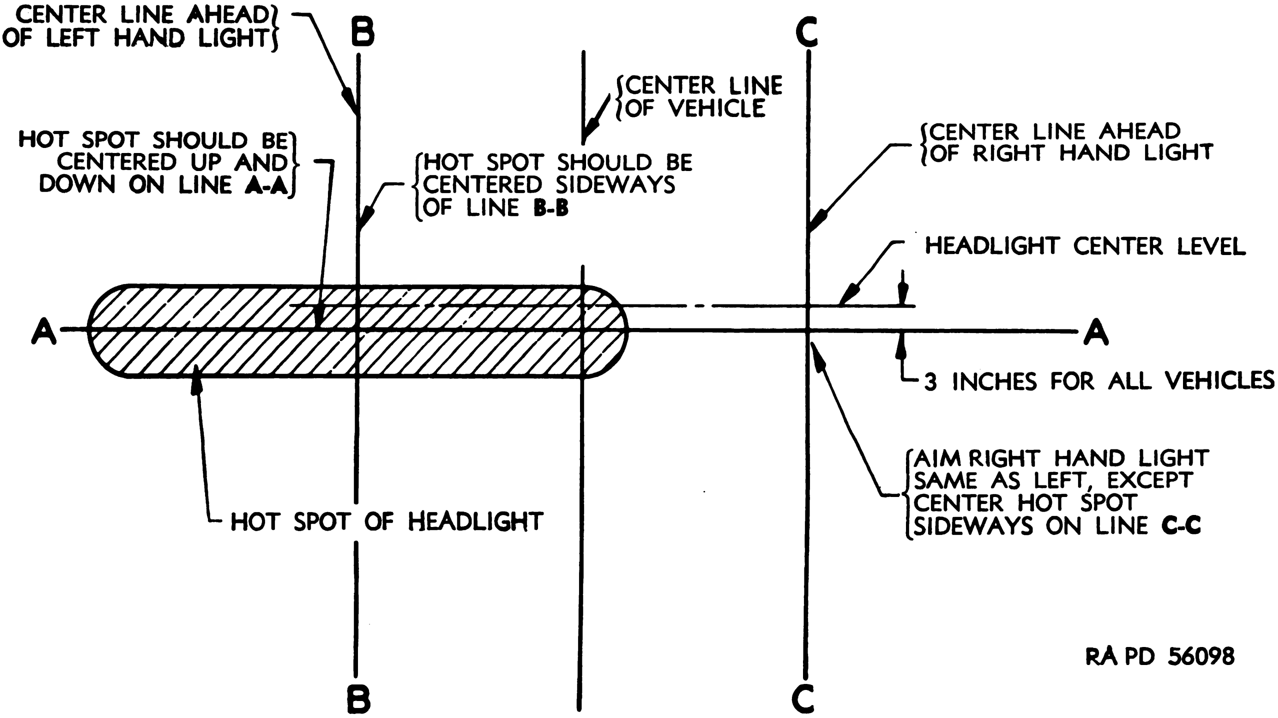

CENTER LINE AHEAD OF LEFT HAND LIGHT
B
C
CENTER LINE OF VEHICLE
HOT SPOT SHOULD BE CENTERED UP AND DOWN ON LINE A-A
HOT SPOT SHOULD BE CENTERED SIDEWAYS OF LINE B-B
CENTER LINE AHEAD OF RIGHT HAND LIGHT
HEADLIGHT CENTER LEVEL
A
A
3 INCHES FOR ALL VEHICLES
AIM RIGHT HAND LIGHT SAME AS LEFT, EXCEPT CENTER HOT SPOT SIDEWAYS ON LINE C-C
HOT SPOT OF HEADLIGHT
RA PD 56098
B
C

Figure 249. Headlight aiming pattern.

when it is mounted in the headlights, one filament will be at the focal point of the reflector, and the other filament will be slightly out of focus so that the rays will be deflected downward. Depressing the beam is accomplished by a foot-operated switch which changes the current from one filament to the other.

168. Switches

a. Headlight.

(1) Two headlight controls are usually provided, one switch being mounted on the instrument panel and another switch on the toeboard near the clutch pedal position. A light control switch for instrument panel mounting is usually of the plunger type with three positions. In the first position, with the plunger knob pushed all the way in, headlights, parking lights, taillights, and instrument lamps are all off; that is, the switch is open. In the second, or middle, position the parking lights, taillights, and instrument lamps are turned on. In the third position, with the plunger knob pulled all the way out, headlights, taillights, and instrument lamps are on. With the plunger knob in this position, it is possible to change the headlights for either upper or depressed beam by pressing the foot dimmer switch on the toeboard. Thus, it is possible for the driver to shift from the driving beam to the passing beam without taking his hands from the steering wheel. This is highly desirable at high speeds. Usually, a small indicating lamp is provided on the instrument panel; this will light when the upper driving beam is on, giving the driver an indication of which beam is being used.

(2) Some manufacturers provide four positions on the instrument panel light switch. Two positions are then provided for the selection of the proper light beam. When the instrument panel switch is in the third, or depressed, beam position, the foot dimmer switch is inoperative; thus, the driver can maintain the depressed beam when there is difficulty in distinguishing which beam is in use. The foot dimmer switch is operative for the selection of the proper beam when the knob is in the fourth position, or all the way out.

(3) A new light switch used on late-model vehicles is shown in figure 250, with the various switch positions diagrammed. An important feature of this switch is that it reduces the possibility of accidentally turning on the lights in a blackout. The mechanical switch has to be raised and held in that position while the main switch is turned for bright lights. This, and the other switch positions, are noted in figure 250. With the main switch off, no lights are on. It can be turned to the left, without operating the mechanical switch, to get blackout marker lights (including blackout taillights and stop lights), and blackout driving lights. But for stop lights for daylight driving, or normal bright lights for ordinary night driving, you must first lift the mechanical switch lever and then turn the main switch lever to the right (fig. 250). The auxiliary switch gives panel lights when the main switch is in any of its ON positions. But it will give parking lights only when the main switch is in service drive (to extreme right). When the main switch is off, the auxiliary switch should not be moved from the OFF position.

(4) The foot dimmer switch is located either to the left of the clutch pedal or between the clutch and brake pedals, so that the left foot can be used to operate the switch. The switch is operated by depressing the button to the full depth, which rotates a contactor cam, breaking one contact and making the other. Depressing the button a second time restores the switch to its original position. The switch is designed so that the contacts overlap; that is, one contact is made before the other is broken, so that both beams will not be off at the same time. This eliminates any possibility of headlamps being out while changing beams.

b. Stoplight.

(1) As the function of the stoplight, mounted at the rear of the vehicle, is to warn any following vehicle that the driver in-

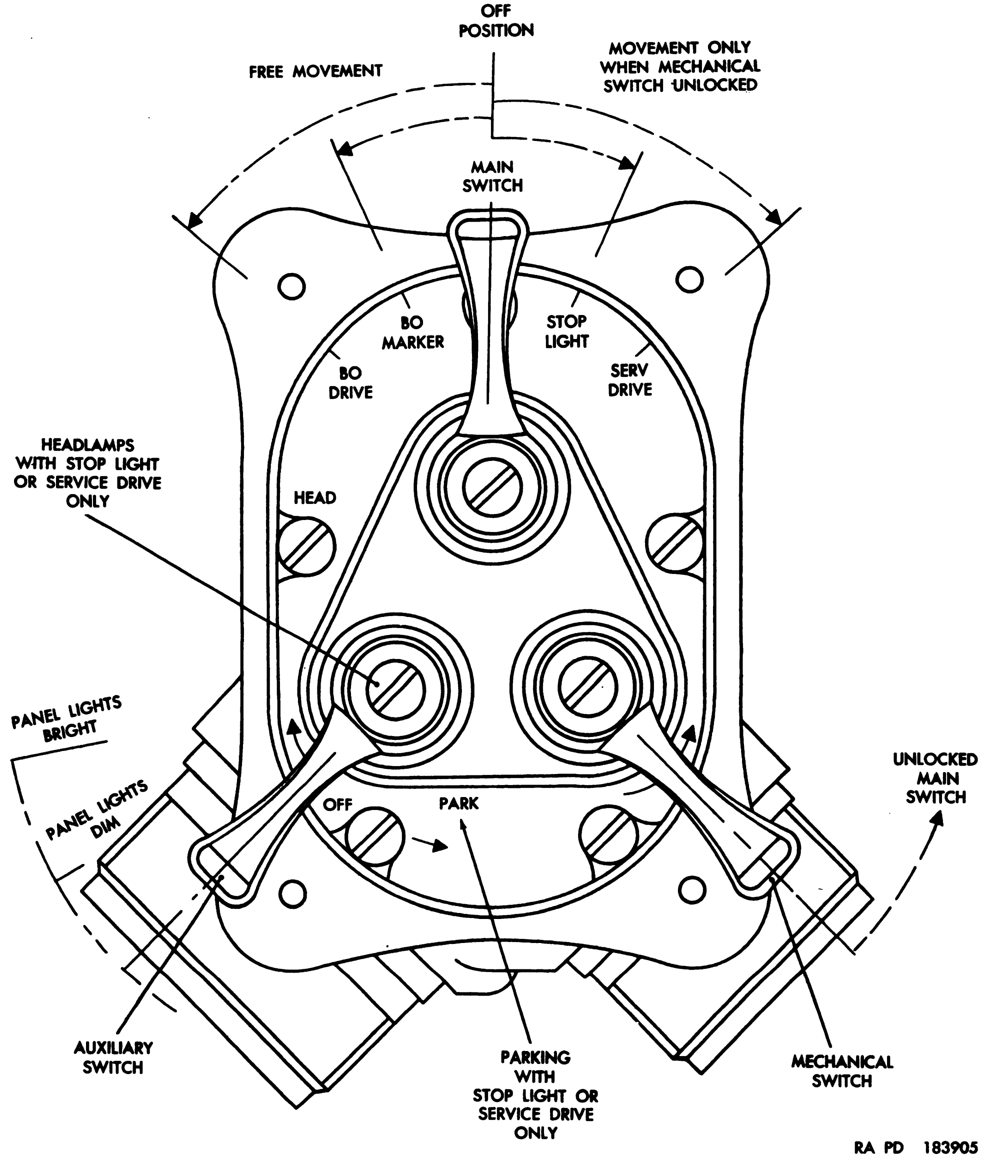

OFF POSITION
FREE MOVEMENT
MOVEMENT ONLY WHEN MECHANICAL SWITCH UNLOCKED
MAIN SWITCH
BO MARKER
STOP LIGHT
BO DRIVE
SERV DRIVE
HEADLAMPS WITH STOP LIGHT OR SERVICE DRIVE ONLY
HEAD
PANEL LIGHTS BRIGHT
PANEL LIGHTS DIM
OFF
PARK
UNLOCKED MAIN SWITCH
AUXILIARY SWITCH
PARKING WITH STOP LIGHT OR SERVICE DRIVE ONLY
MECHANICAL SWITCH
RA PD 183905

Figure 250. Light switch positions.

tends to stop or slow down, the stoplight should be so mounted and its brilliance such that it may be readily noticed either day or night. For safety, operation of the stoplight should also be automatic so that special attention is not required by the driver. The stoplight is expected to go on whenever the brakes are applied to slow down or stop the vehicle.

(2) Two types of stoplight switches have been generally adopted, one for use with mechanical brake systems and the other for use with hydraulic or air-operated brake systems.

(3) The operation of the stoplight switch must be coincidental with the operation of the brake pedal. In the mechanical switch, the contacts are closed by a linkage connection to the brake pedal. The hydraulic switch unit is connected directly to the master cylinder so that, when the brakes are applied, the fluid pressure will operate the switch. The stoplight switch on air-brake systems is operated from the air pressure of the system.

c. Blackout Light. Vehicles provided with blackout lights have a special blackout-light switch which incorporates the operation of the service lights and blackout lights in one unit. This switch

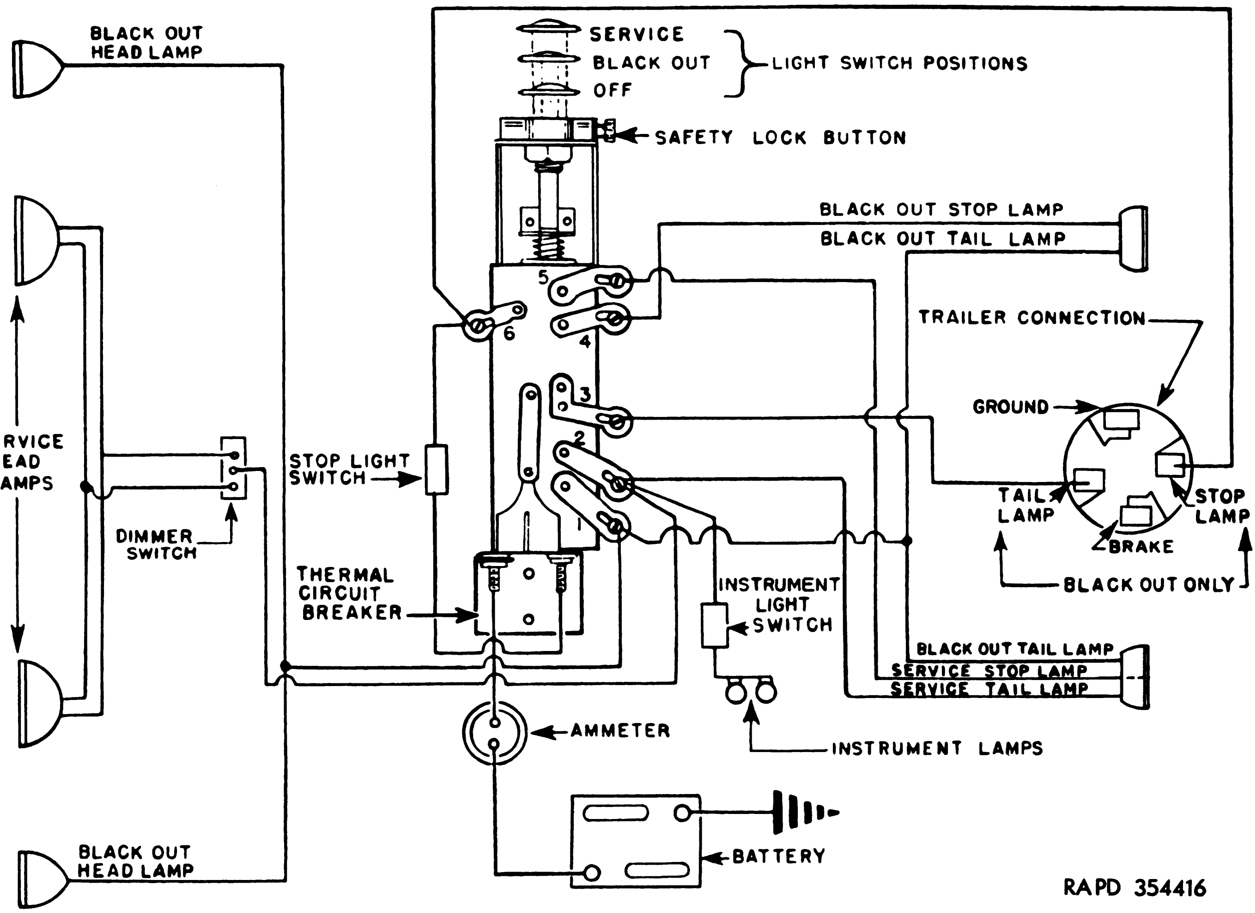

BLACK OUT HEAD LAMP
SERVICE
BLACK OUT
OFF
LIGHT SWITCH POSITIONS
SAFETY LOCK BUTTON
BLACK OUT STOP LAMP
BLACK OUT TAIL LAMP
5
6
4
3
2
1
TRAILER CONNECTION
GROUND
SERVICE HEAD LAMPS
STOP LIGHT SWITCH
TAIL LAMP
STOP LAMP
BRAKE
DIMMER SWITCH
BLACK OUT ONLY
THERMAL CIRCUIT BREAKER
INSTRUMENT LIGHT SWITCH
BLACK OUT TAIL LAMP
SERVICE STOP LAMP
SERVICE TAIL LAMP
AMMETER
INSTRUMENT LAMPS
BATTERY
BLACK OUT HEAD LAMP
RAPD 354416

Figure 251. Blackout light switch and connections.

is shown in figure 251 with its connections to the various units in the lighting system. The plunger knob has three positions: OFF, BLACKOUT LIGHTS, and SERVICE LIGHTS. In its second, or middle, position the switch turns the blackout lights on, keeping all other lights off. The plunger knob cannot be pulled out to its third position until the safety-lock button is pushed in. This safety feature prevents any lights visible from above being accidentally turned on during a blackout. In the third position, with the plunger knob pulled all the way out, the service lamps are on and operate normally as described in *a* above. A trailer connection is provided to operate lamps on the rear of the trailer. These are lit when the switch is in both the second and third positions. Blackout driving and front marker lights are shown in figure 252.

169. Other Lamps

a. Instrument Lights. Ordinarily, indirect lighting is used for the instrument lamps, which light whenever the lighting switch is in any of the ON positions. Many cars are equipped with an instrument panel lamp switch so that the instrument panel lamps can be turned off when desired.

b. Dome Lights. Practically all closed motor vehicles make use of dome or tonneau lights. These are ordinarily controlled by means of a switch on a body post near the right door.

c. Parking Lights.

(1) The smaller lights used for parking are sometimes located immediately above or below the main headlights. The parking light housing is usually constructed as a part of the main headlight housing.

(2) Side lights sometimes serve as parking lights, in which case, a separate housing is used.

(3) A smaller lamp, located within the main headlight and above the main headlight lamp, has frequently been used to provide a parking light. A 4- or 6-candlepower lamp, or smaller, is used for a parking light.

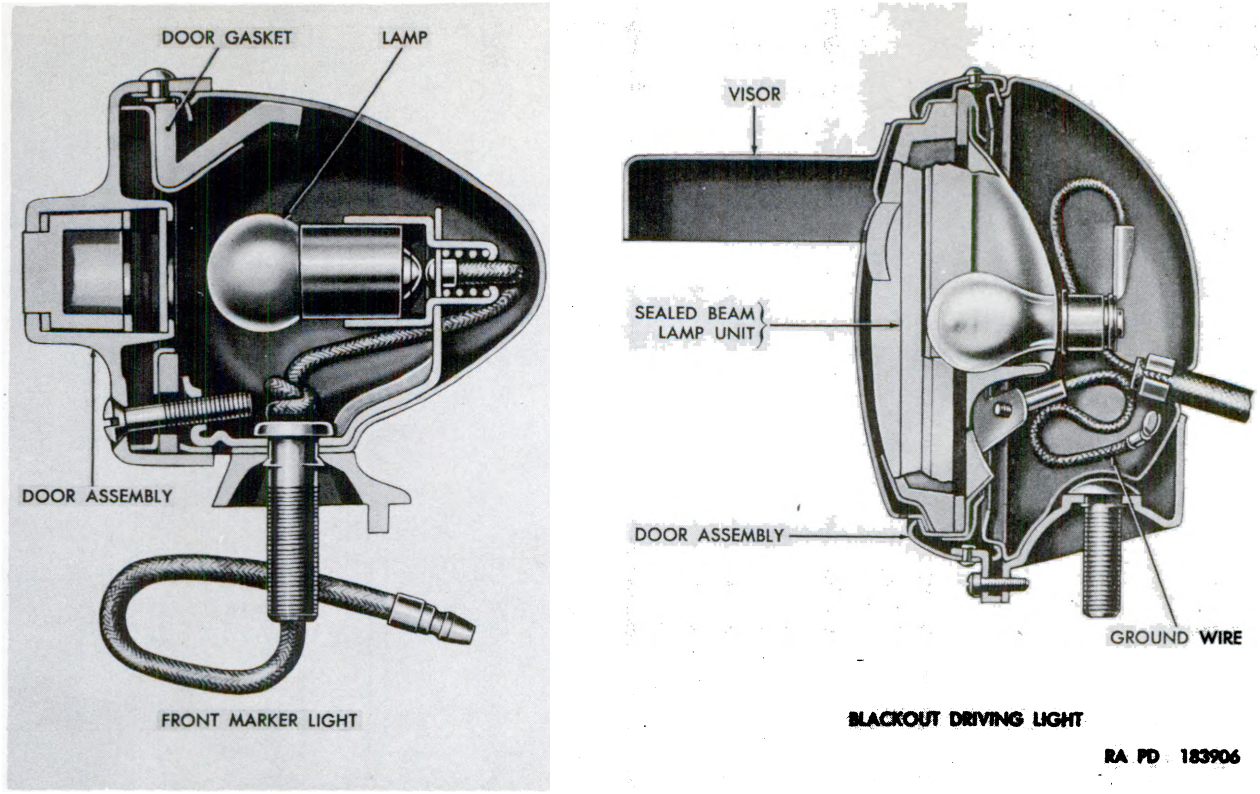


Figure 252. Blackout driving and front marker lights.

d. Taillight and Stop Lights. Taillight and stop lights are ordinarily combined, with two lamps contained in a single housing with a red lens. A larger lamp (about 15 candlepower) is used for the stop light and a smaller lamp (about 3 candlepower) for the taillight. Taillight and stop lights are sometimes enclosed in a single lamp having a double filament. Taillights light whenever the lighting switch is in any of the ON positions.

e. Backing Lights. Occasionally a backing light is used, mounted so as to direct light to the rear of the vehicle. It is arranged and wired so that a switch turns on the lamp when the gearshift lever is put into reverse position.

f. Spotlights. Spotlights are similar in construction to the headlights. They are designed to project a beam for a great distance ahead and are constructed so that the light can be aimed by the vehicle operator. They are valuable for detecting pedestrians at a safe distance, or observing the condition of the roadway to the sides, and for reading roadmarking signs.

g. Auxiliary Driving Lights. To improve the lighting of the roadway without throwing glaring light rays into the eyes of approaching drivers and pedestrians, auxiliary driving lights are sometimes used. They are designed to be mounted on the front of the car on the headlight tie rod, on the fender, or on the horns of the car frame. Spotlights may be used for this purpose and mounted similarly.

h. Indicating Lights. Buses and trucks are usually provided with lights to indicate their width or length. These lights are provided with red, yellow, or green lenses to attract the attention of approaching drivers. The lights are required by the Interstate Commerce Commission, and should be arranged and operated in accordance with their instructions.

i. Blackout Lights.

(1) It is a difficult problem to provide a lighting system for night driving that will illuminate the roadway sufficiently to drive at reasonable speeds with a fair degree of safety and, at the same time, prevent effective observation by the enemy. Intensive study is being given to the use of luminous markers placed on roadsides and on vehicles equipped with special driving lights which illuminate the markers, yet are not vis-

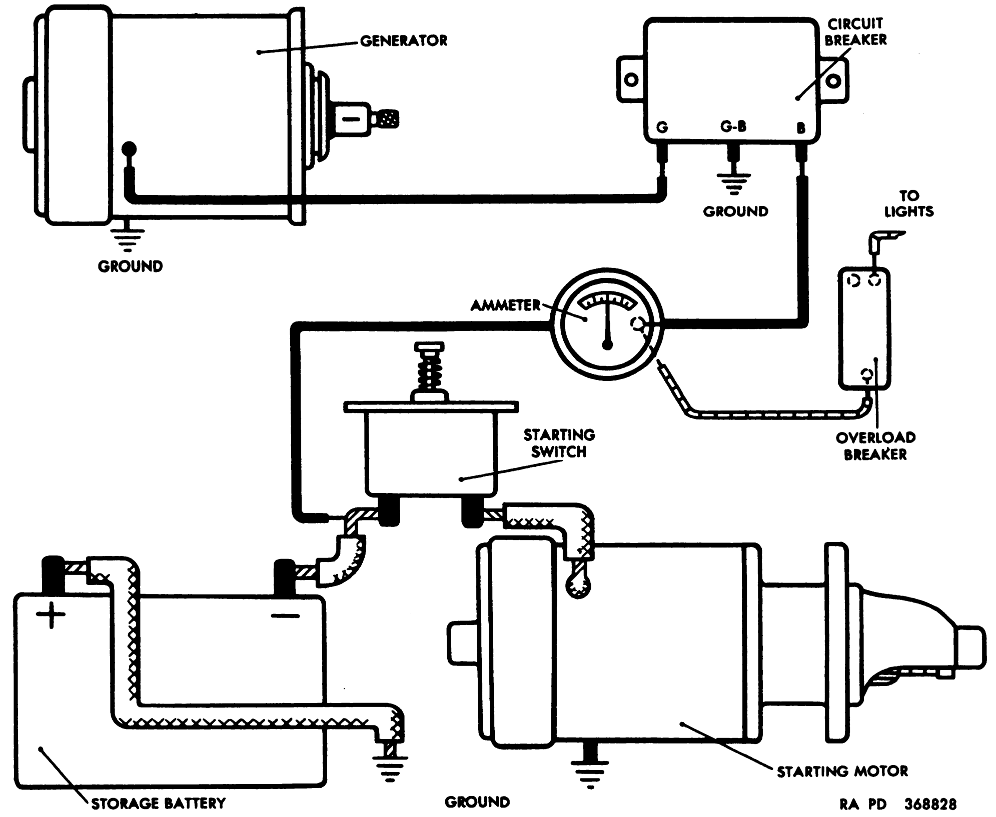


Figure 253. Simplified wiring diagram showing location of overload breaker (circuit breaker or fuse) in electrical system.

ible at a distance. The problem of proper night lighting and the use of marking devices depend largely on the selection of drivers. Two men who see equally well in daylight may have quite different relative vision at night. Tests must be made for the selection of men who have acute vision at night. At the present time, small blackout lights are used. Further research will probably bring other developments.

(2) Blackout lights are used to enable a convoy to move at night without being observed from the air. These lights provide sufficient illumination to enable units in a convoy to keep in line while progressing at slow speeds. Two blackout headlights, two blackout taillights, and a blackout stoplight are provided for this illumination. All other lights in the vehicle are off when the blackout lights are lit.

(3) Small housings, somewhat similar to passenger car parking light housings, are used with small lamps that produce subdued lighting. A shutter, somewhat like a venetian blind, is placed in front of the lens to prevent any light from being projected upward.

170. Overload Breakers

Besides limiting the current by current regulation, the battery and wiring should be protected against excessive loads which might occur due to shorts or grounds in the wiring system. Such protection may be secured by a current limiting circuit breaker or a single fuse. The location of an overload breaker in the electrical system is shown in figure 253.

a. Circuit Breaker.

(1) The circuit breaker is a protective device designed to open the circuit when a current in excess of what it is intended to carry passes through its windings. All current for lights and accessories pass through it. It is similar in construction to the cutout, but opens the circuit rather than closes it. If there is a ground or

other trouble in the circuit, the rush of current will start the circuit breaker vibrating and in this way it indicates that there is something wrong in the system. The device breaks the circuit at about 25 amps but after opening, allows only about 5 amps to pass through, which keeps it vibrating. Thus the circuit breaker protects the battery from rapid discharge when trouble develops. The circuit breaker will continue to vibrate until the trouble is found and corrected.

(2) In all types of circuit breakers, the short circuit must be removed before the breaker can be reset. The short circuit can be easily located by disconnecting each circuit separately until the circuit breaker stops vibrating.

(3) Some automatic breakers do not vibrate, but have a "telltale" light placed across the contacts. This light, generally placed where it is visible to the operator, is protected by a resistance. When the circuit breaker contacts are opened by excessive current, the light flashes on. There is generally sufficient current flowing through the relay coil with the lamp in series to hold the contact arm of the circuit breaker down until the short is removed. After removing the short, it may be necessary to turn off all lights for an instant to permit the relay to reset itself and extinguish the telltale light.

b. Fuse. A common method of protection is to use a fuse in the lighting circuit. Whenever there is an excessive current through the lighting circuit, the fuse will burn out and open the circuit. The short circuit should be removed before the fuse is replaced. The disadvantages of using a fuse are that the circuit must be traced to locate the trouble and that a burned-out fuse must be replaced. However, it provides much cheaper protection to the system.

CHAPTER 11

INSTRUMENTS, GAGES, AND ACCESSORIES

171. Instrument Panel

The instrument panel is usually placed so that the instruments may be easily read by the driver. They inform the driver of the approximate speed, engine temperature, oil pressure, rate of charge or discharge of the battery, amount of fuel in the fuel tank, distance traveled, and the time. Certain controls frequently are mounted on the instrument board, such as throttle, choke, starter, heater, windshield wiper, and others.

172. Ammeter

a. The ammeter is used to indicate the amount of current flowing to and from the battery. It does not give an indication of total generator output because other units in the electrical system besides the battery are supplied by the generator. If it shows a 10-ampere discharge, it indicates that a 100 ampere-hour battery would be discharged in 10 hours; that is, 10 amps flowing for 10 hours.

Note. Some later model wheeled vehicles have replaced the ammeter with a "battery generator indicator" that does not give a calibrated reading but rather shows ranges such as by colors or bands.

b. Current flowing from the storage battery to the starting motor is never sent through the ammeter, since the great quantities used (200 to 600 amps) cannot be measured on an instrument of such limited capacity. In the usual type of ammeter, all the current flowing to and from the battery, except for starting, is actually sent through a coil to produce a magnetic effect which deflects the ammeter needle in proportion to the amount of current. This coil is matched to the maximum current output of the generator and this varies with different applications.

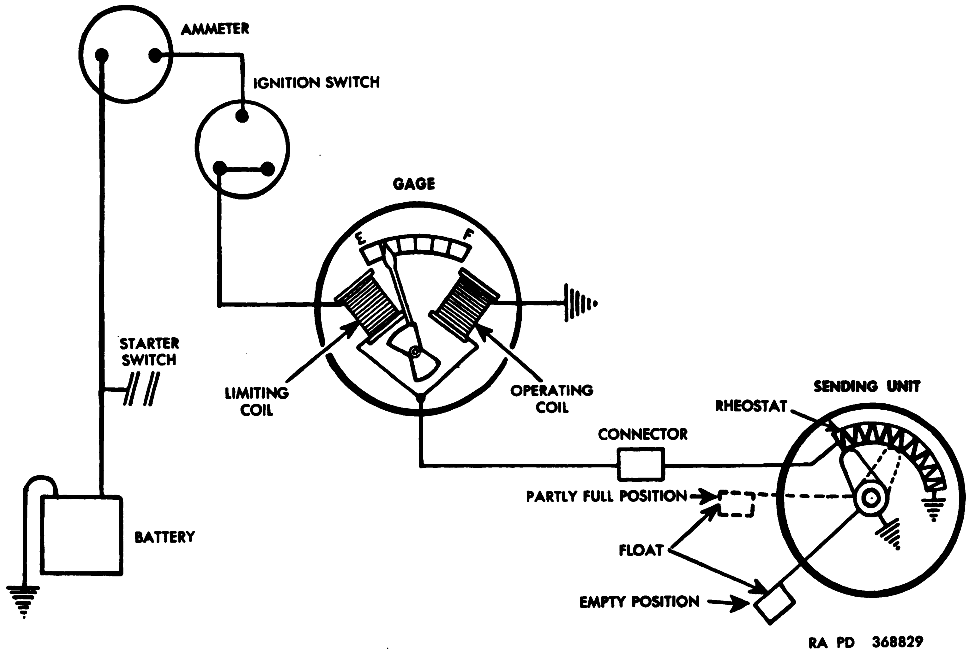
173. Fuel Gage

Most fuel gages are electrically operated and are composed of two units: the gage, mounted on the instrument panel; and the sending unit mounted on the fuel tank. The ignition switch is included in the fuel gage circuit so that the electrical fuel gage operates only when the ignition switch is on. Operation of the electrical gage depends on either coil action or thermostatic action.

a. Coil Type.

(1) The electrical circuit for a fuel gage is shown in figure 254 in which the coil type gage is illustrated. Indication of the fuel level is accomplished by the variation in magnetic effect of two coils on a pointer, caused by a change of resistance in the sending unit. The rising or falling float in the fuel tank moves the arm of a rheostat or variable resistance.

(2) Current from the battery passes through the limiting coil to the common connection between the two coils, which is the lower terminal on the gage. At this point, the current is offered two paths, one through the operating coil of the gage and the other over the wire to the sending unit. When the fuel tank is empty, the grounded rheostat arm on the rheostat cuts out all the resistance in the sending unit. Most of the current will pass through the sending unit circuit, because of the low resistance, and only a very small portion through the operating coil of the gage. As a result, this coil is not sufficiently magnetized to move the indicating pointer in the gage which is held at the empty position by the limiting coil. If the fuel tank is partially full, the float of the sending unit rises on the surface of the fuel and moves the rheostat arm over the resistance, putting resistance into the sending unit circuit as indicated by the broken lines in figure 254. More current will then pass through the operating coil to give a magnetic pull on the pointer, which overcomes some of the pull of the limiting coil. When the tank is full, the sending unit circuit contains



RA PD 368829

Figure 254. Coil-type fuel gage circuit.

its maximum resistance to the flow of current. The operating coil will then receive its maximum current and exert a maximum pull on the pointer to give a full tank reading. As the tank empties, the operating coil loses some of its magnetic pull while the limiting coil still has approximately the same pull, so that the pointer is pulled toward a lower reading.

(3) This type of gage consumes very little current, about one-eighth of an ampere. Since the operation of this gage depends on the difference in the magnetic effect between two coils, variations in the battery voltage will not cause an error in the gage reading.

b. Thermostatic Fuel Gage.

(1) The gage, with the dial removed, of one type of thermostatically operated electric fuel gage is shown in figures 255 and 256. This gage operates by the electrical heating of bimetal thermostat blades. The blades "A" and "B" are heated by the insulated resistance wire wound around them. Current enters the fuel gage at the center terminal on the back of the gage. From there it passes through the contact points "E," then up the blade "C," and down the blades "A" and "B" to a point near the end of each blade where the resistance heater wire is welded to them. It then passes up through the resistance wire on each blade to the terminals marked Nos. 1 and 2. These terminals are both connected by separate wires to each end of a rheostat in the sending unit.

(2) When the sending unit float is all the way down, all of the rheostat resistance (25 ohms) is in terminal No. 2 circuit and none is in terminal No. 1 circuit. Most of the current will flow through terminal No. 1 circuit and the bimetal blade "A." This current through the resistance wire on blade "A" will heat the blade, making it deflect to the left (in fig. 255) and push the indicator pointer to empty.

(3) When the sending unit float is raised all the way, the rheostat resistance is zero in terminal No. 2 circuit and 25 ohms in terminal No. 1 circuit. The resistance wire around the bimetal blade "B" will then receive most of the current and become heated. Blade "B" deflects to the right (in fig. 256) when heated, so that it pushes the gage pointer toward full.

(4) The outside bimetal blades "C" and "D" compensate for the effect of outside air

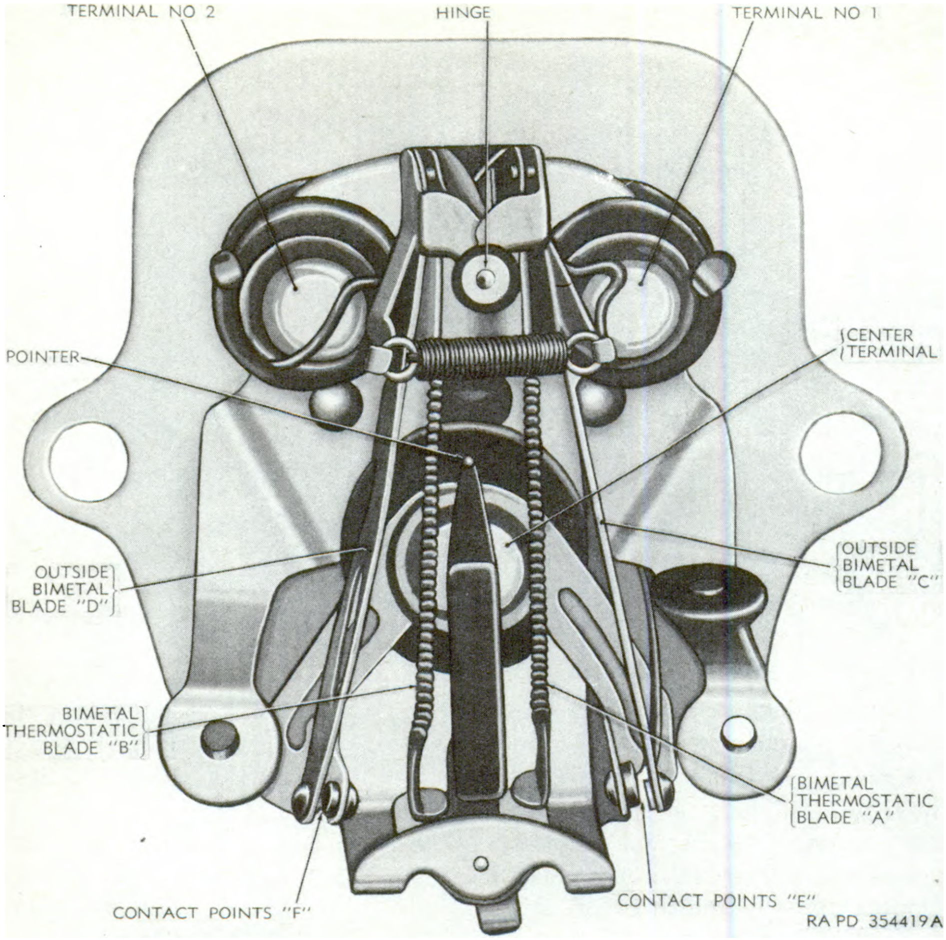

TERMINAL NO 2
HINGE
TERMINAL NO 1
POINTER
CENTER TERMINAL
OUTSIDE BIMETAL BLADE "D"
OUTSIDE BIMETAL BLADE "C"
BIMETAL THERMOSTATIC BLADE "B"
BIMETAL THERMOSTATIC BLADE "A"
CONTACT POINTS "F"
CONTACT POINTS "E"
RA PD 354419A

Figure 255. Instrument panel bimetal thermostatic fuel gage (dial removed).

temperature on blades "A" and "B" and also compensate for the variation in battery voltage. The combined deflection of the blades, due to the temperature reached when 5 volts is across the gage, opens the contact points "E." Below 5 volts, the contact points do not open. Above 5 volts, they open and close intermittently to maintain constant input to the gage. The insulated contact points "F" merely act as an anchor for the entire operating mechanism for the purpose of temperature compensation.

c. *Thermostatic Gage and Sending Unit Types.*

(1) Another type of thermostatic electric fuel gage has bimetal blades in both gage and sending units. This type gage may also be used as a temperature or oil pressure gage by using changes in pressure or temperature to operate the movable grounded contact in the sending unit.

(2) When the tank is empty and the float is down as shown in figure 257, diagram 1, the two contacts in the sending unit are just touching. Current flows through the resistance heater wires of both gage and sending units, causing the bimetal blades to bend. Bending of the bimetal blade in the sending unit separates the contacts to break the circuit. The heater wire cools when the current stops flowing, and the bimetal blades return to their original position. Contact is again made and the cycle of operation is repeated approximately every second. Opening and closing of the contacts gives an intermittent flow of current which does not heat the gage blade sufficiently to bend it. The blade then holds the pointer at the empty reading.

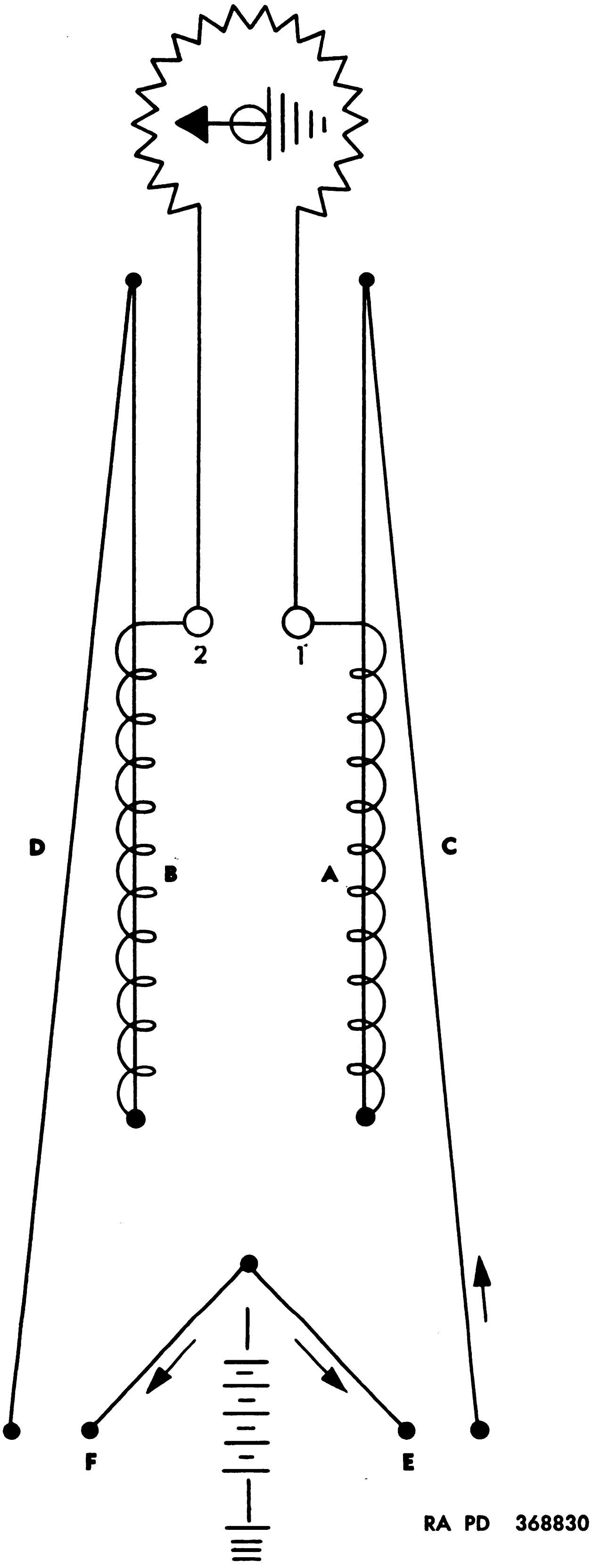


Figure 256. Schematic drawing of thermostatic fuel gage and sending unit.

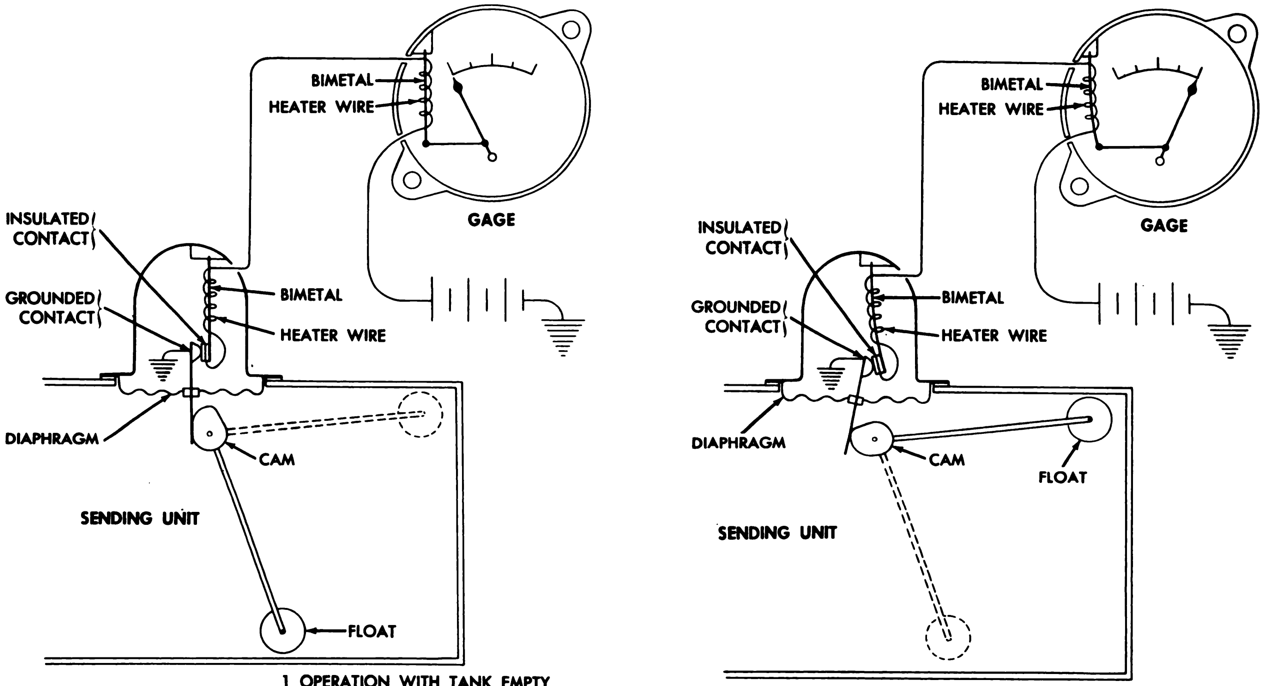
(3) When the tank is full, the float is at the top and the cam takes the position shown in figure 257 diagram 2. In this position, the cam pushes the grounded contact against the insulated bimetal contact, bending the bimetal blade in the sending unit. Since the bimetal is then under a strain, the current must flow longer to bend it sufficiently to open the contacts. The longer flow of current will then cause a bending of the bimetal blade in the gage unit and push the pointer over to the full position.

(4) The contacts open and close fast enough to give a steady reading by the pointer. The maximum current requirement for a full reading is less than one-fourth ampere. This type of gage is not affected by variations of battery voltage and is compensated for outside air temperature variations.

d. Hydrostatic Fuel Gage. The hydrostatic fuel gage consists of a dash gage and a sending unit connected by an air tube. In operating condition, the air tube and air chamber of the sending unit and the air tube connecting the sending unit with the gage are filled with air. The fuel tries to rise to the same level in the sending unit as it is in the tank, but this is impossible because of the air trapped between the bottom of the sending unit and the liquid in the gage. The pressure is thus transmitted by means of the air column in the air tube to the gage, where it forces the liquid of the gage down in the brass tube and up in the glass indicating tube. The cup and air-delivery tube mounted in the tank have no part in the reading of the gage, but act only as a means of supplying air to the air chamber to keep it full.

174. Speedometer and Tachometer

a. General. A speedometer (fig. 258) is used to indicate vehicle speed in miles per hour and to record distance traveled, by means of an odometer. The speedometer may be driven either by a flexible shaft or by electrical means. The type using a flexible shaft has a set of gears in the vehicle transmission. This set of gears drives the flexible shaft and the flexible shaft, in turn, drives the rotating part of the speedometer (fig. 259). The gears are designed for the particular vehicle model and take into consideration the tire size


BIMETAL
HEATER WIRE
GAGE
INSULATED CONTACT
GROUNDED CONTACT
BIMETAL
HEATER WIRE
DIAPHRAGM
CAM
SENDING UNIT
FLOAT
BIMETAL
HEATER WIRE
GAGE
INSULATED CONTACT
GROUNDED CONTACT
BIMETAL
HEATER WIRE
DIAPHRAGM
CAM
FLOAT
SENDING UNIT

1 OPERATION WITH TANK EMPTY

2 OPERATION WITH TANK FULL

RA PD 368831

Figure 257. Fuel gage in which both gage and sending units are thermostatically operated.

and rear axle ratio. The flexible shaft consists of an outer casing and the inner drive core (fig. 260). The speedometer driven by electrical means uses two separate units, a generator (or transmitter), and an indicator, connected by electrical wires. Details of their operation are outlined in *d* below.

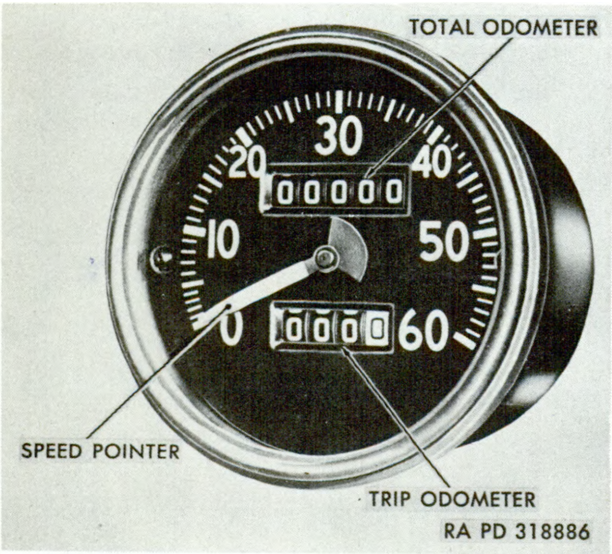

TOTAL ODOMETER
SPEED POINTER
TRIP ODOMETER
RA PD 318886

Figure 258. Speedometer.

b. Tachometer. The tachometer (fig. 261) is ordinarily used to indicate vehicle engine speed. It is similar to the speedometer, except that the face dial indicates revolutions per minute instead of miles per hour. The tachometer may be driven either by a flexible shaft or by electrical means. The type using a flexible shaft is driven, through the shaft, from the vehicle generator, camshaft, or distributor shaft. The tachometer driven by electrical means uses two separate units, a generator (or transmitter) and an indicator, connected by electrical wires. An odometer is often incorporated in the tachometer to record mileage.

c. Operation of Speedometer and Tachometer (Flexible-Shaft-Driven Type). Even though the internal parts of the various instruments differ in construction and appearance, they all incorporate the same basic components and operate on the same principles.

(1) *Speed indicator* (fig. 262). The speed-indicating portion of a speedometer or tachometer of the magnetic type operates on the magnetic principle, and includes a revolving permanent magnet (driven by the flexible shaft). Around this revolving permanent magnet is a station-

ary field plate. (Some instruments have a revolving field plate.) Between the magnet and field plate is a movable speed cup, with the indicating pointer attached to the end of the speed cup staff. As the magnet revolves within the speed cup, it sets up a rotating magnetic field which exerts a pull, or magnetic drag, on the speed cup, making it revolve in the same direction. The movement of the speed cup is retarded and held steady by a hair spring attached to the speed cup staff. The speed cup comes to rest at a point where the magnetic drag is just balanced by the retarding force created by the hair spring. An additional function of the hair spring is to pull the pointer back to zero when the vehicle or engine stops. There is no mechanical connection between the revolving magnet and the speed cup. As the speed of the magnet increases due to vehicle acceleration or (as in the case of a tachometer) to increase in the engine speed, the magnetic drag on the speed cup also increases and pulls the speed cup farther around, thus registering a faster speed by the pointer and face dial. The magnetic field is constant, and the amount of speed cup deflection is at all times proportional to the speed at which the magnet is being revolved.

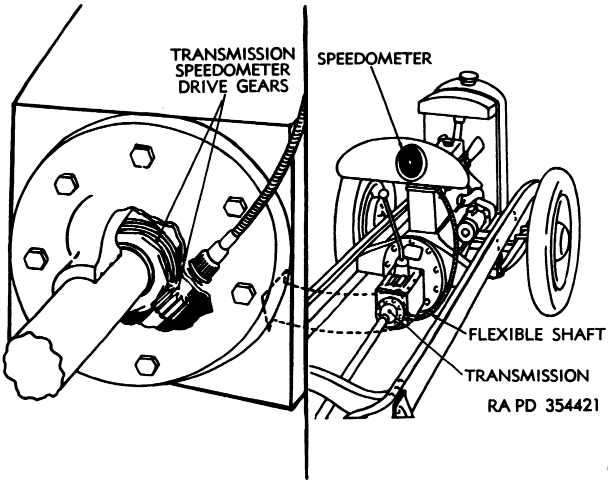


Figure 259. Speedometer installation.

(2) *Odometer operation.*

(*a*) *Total odometer* (fig. 263). The total odometer is driven through a series of gears originating at a spiral gear out on the magnet shaft. This gear, known as the *first gear*, drives an intermediate *second gear* and a *third gear* which is connected to a *fourth gear* at the odometer. The fourth gear turns the odometer through a series of star pinion gears inside the odometer dials, or figure wheels. The total odometer usually has five figure wheels, or dials, and is so constructed and geared that as any one wheel finishes a complete revolution it turns the next figure wheel to the left one-tenth of a revolution. Most models record to 99,999 miles, then automatically zero themselves.

(*b*) *Trip odometer* (fig. 263). The trip odometer is also driven by the third gear, through the trip odometer drive gear and another gear at the trip odometer. The trip odometer usually has four figure wheels, and is so constructed that as any one figure wheel finishes a complete revolution, it turns the next figure wheel to the left one-tenth of a revolution. The figure wheel

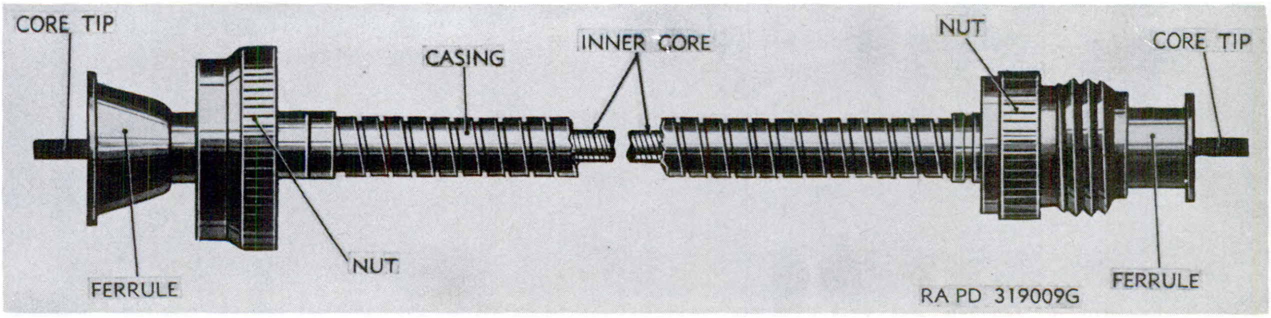


Figure 260. Speedometer and tachometer flexible drive shaft.

on the extreme right registers in tenths of a mile. Most models record to 999.9 miles, then automatically zero themselves. Also, they are usually equipped with a reset mechanism so that the mileage on the trip odometer can be reset as desired.

d. Operation of Speedometer and Tachometer (Electrical Type). The electrical type of speedometer and tachometer (fig. 264) utilize small generators (called transmitters) driven mechanically as explained in (1) and (2) below. The voltages produced then cause small motors in the indicator assembly to operate so that the indicator assembly indicates vehicle and engine speeds.

(1) *Electrical operation.* The speedometer transmitter is driven from the final drive of the vehicle. The tachometer transmitter is driven from an engine accessory

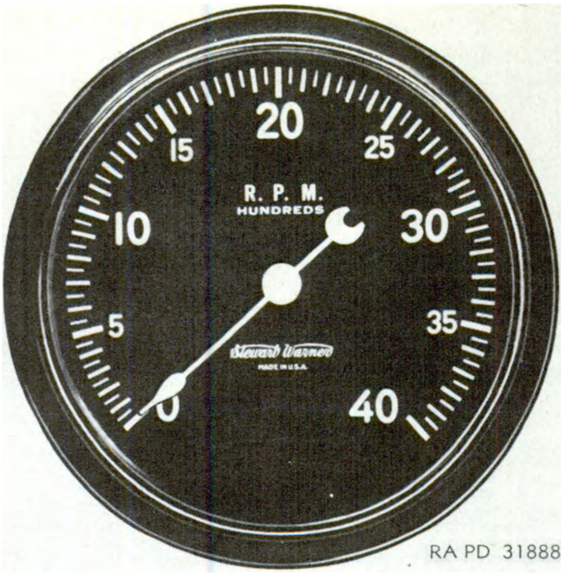

20
15
25
R. P. M.
HUNDREDS
10
30
5
35
0
40
Stewart Warner
MADE IN U.S.A.
RA PD 318889

Figure 261. Tachometer.

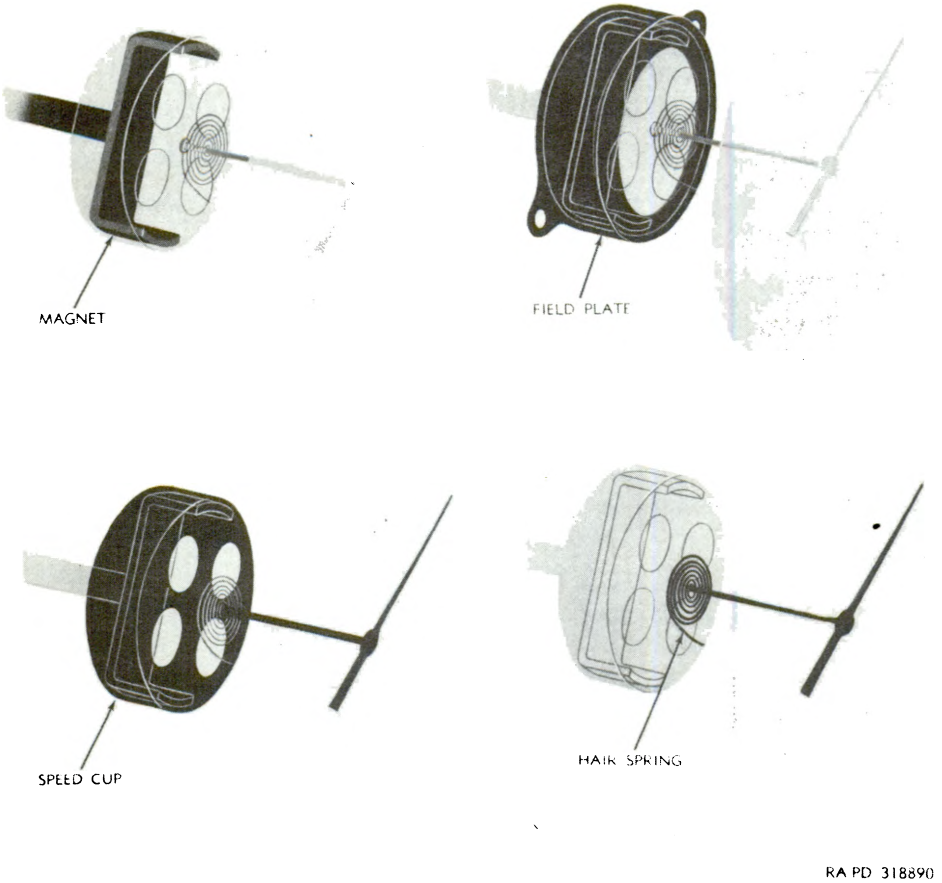

MAGNET
FIELD PLATE
SPEED CUP
HAIR SPRING
RA PD 318890

Figure 262. Phantom view of basic components of speed—indicating portion of speedometer.

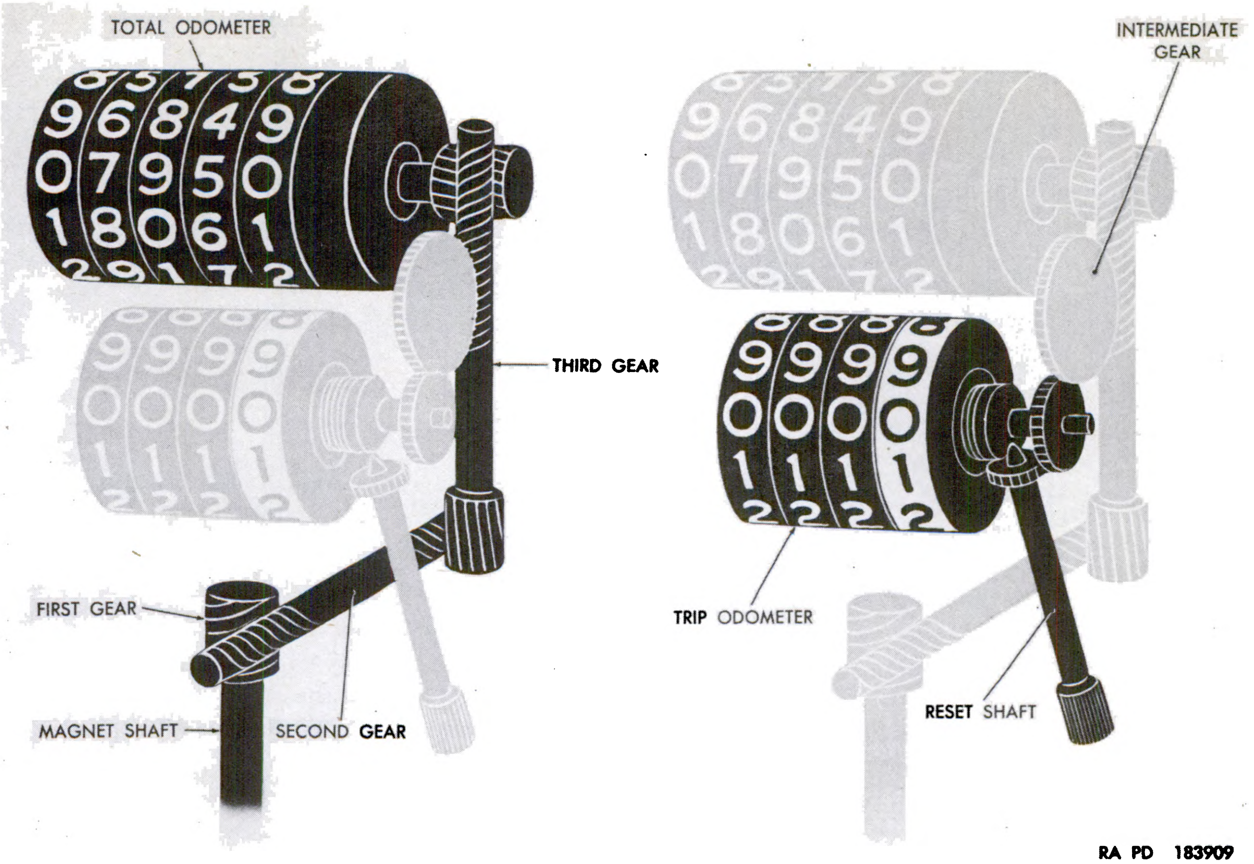


Figure 263. Total and trip odometers—schematic view.

drive (such as the ignition distributor drive). Both transmitters are small generators. Voltage output of each is proportional to speed of rotation. The speedometer-tachometer indicator assembly (fig. 264) contains two synchronous motors. In operation, one of the motors is electrically driven by the speedometer-transmitter generator. The other motor is electrically driven by the tachometer-transmitter generator. Motor speeds are the same as the transmitter-generator speeds after operating speeds are attained. The indicator assembly indicates both vehicle speed and engine speed on a single dial.

(2) *Mechanical operation.* A magnet is mounted on each of the two motor shafts in the indicator. The motor shafts are rotated electrically, as explained, in (1) above. As the motor shaft rotates, the magnet and its lines of force also rotate. The lines of force sweep through the metal wall of the drag-cup, and thereby attempt to make the drag-cup rotate. But the rotation of the drag-cup is restrained by a calibrated hairspring. The rotational drag tends to overcome the spring, however, thereby turning the drag-cup. This turns the pointer on the dial. Rotational drag on the drag-cup increases with increased magnet (and motor shaft) speed. Thus, at higher speeds, the drag-cup is turned farther against the hairspring tension, causing the pointer to move farther on the dial to indicate the higher speed. As speed decreases, the rotational drag on the drag-cup is reduced so the hairspring turns the drag-cup back. The pointer therefore turns back to indicate the lower speed.

175. Oil Pressure Gage

a. Location and Function. An oil pressure gage indicates the oil pressure in the system. Usually, such gages are mounted on the instrument

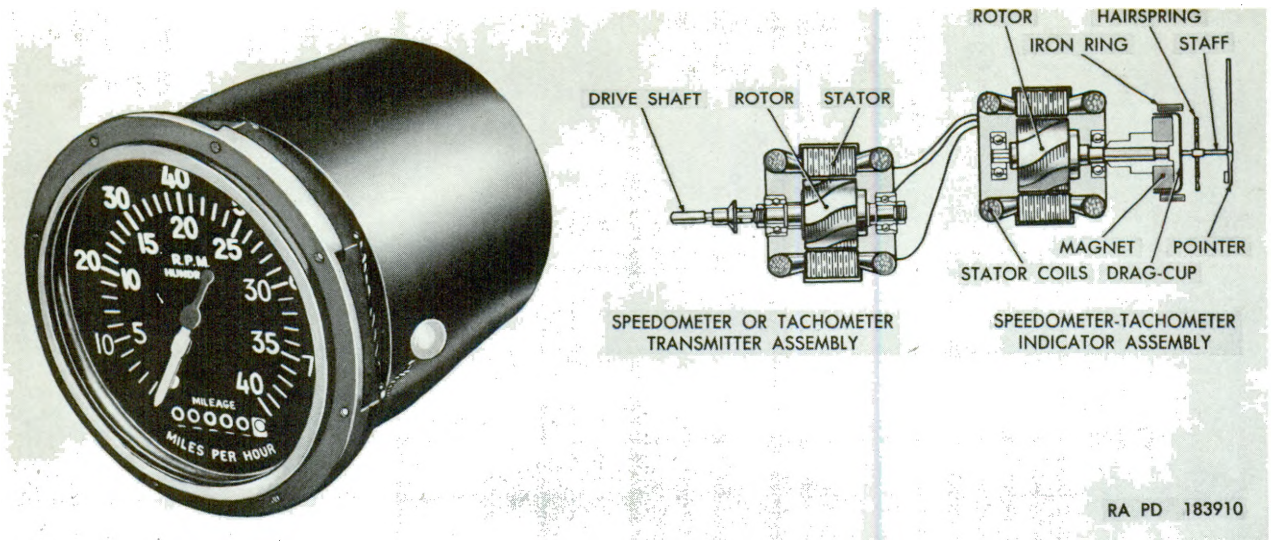


Figure 264. Speedometer-tachometer indicator and electrical circuit of electricaltype speedometer and tachometer.

board and are calibrated to read in pounds per square inch.

b. Operation. Some gages are actuated by the pressure of air trapped above the oil in a very small copper tube connected from the gage to the lubricating system. Air pressure in the connecting tube is maintained by the oil pressure in the system. The operation of the gage itself is based on the use of the Bourdon tube, which is a flexible, semicircular metal tube, elliptically shaped in cross section, with one sealed end and one open end. The open end is connected to the pressure system, and if the pressure of gas or liquid within the tube increases, the tube will tend to straighten itself. As the pressure decreases, the tube will resume its normal semicircular shape. By fixing the open end and allowing the sealed end to move freely, the "straightening" movement of the tube can be used to move a needle across a dial. A simple spring, gear, and lever arrangement serves to return the needle as the pressure is reduced and the tube resumes its shape.

c. Electric-Type Gage. Some vehicles are equipped with electric-type oil pressure gages, which are activated during engine operation by a sending unit connected to the engine oil system gallery. Absence of oil pressure during engine operation indicates a faulty oiling system or inoperative gage circuit, and engine should be immediately stopped.

176. Temperature Gage

A temperature gage, mounted on the dashboard, indicates the temperature of the coolant in the water jacket and may operate either electrically or on the principle of the Bourdon tube.

a. Bourdon Tube. When the principle of operation is the Bourdon tube, described in paragraph 175*b*, it is actuated by pressure conducted to it from a bulb which is screwed into the water jacket of the engine. The heat of the water affects the liquid in the bulb. This liquid vaporizes at a very low temperature and the gas flows through the capillary, a very small tube connecting the bulb to the gage. The greater the heat, the more vapor given off and the greater the pressure; thus, the higher temperature is indicated on the gage.

b. Electric Temperature Gage. The electric temperature gage functions on much the same principle as the coil-type fuel gage described in paragraph 173*a*. As in the fuel gage, the temperature gage consists of two coils at right angles to each other with an armature at the intersection of the coil axis. Connected to the armature is a pointer. Essentially, the sending unit is a resistor whose resistance varies inversely with the temperature of the engine. When the engine temperature is high, the resistance is low; when the temperature is low, the resistance is high. On the low temperature side of the gage unit, the coil is connected directly across the battery. Thus, there exists a constant magnetic strength in that coil which attracts the armature and pointer to the low temperature side. However, the coil on the high temperature side is connected in series with the resistance of the sending unit and across the battery. Since the resistance varies with the temperature, the coil's

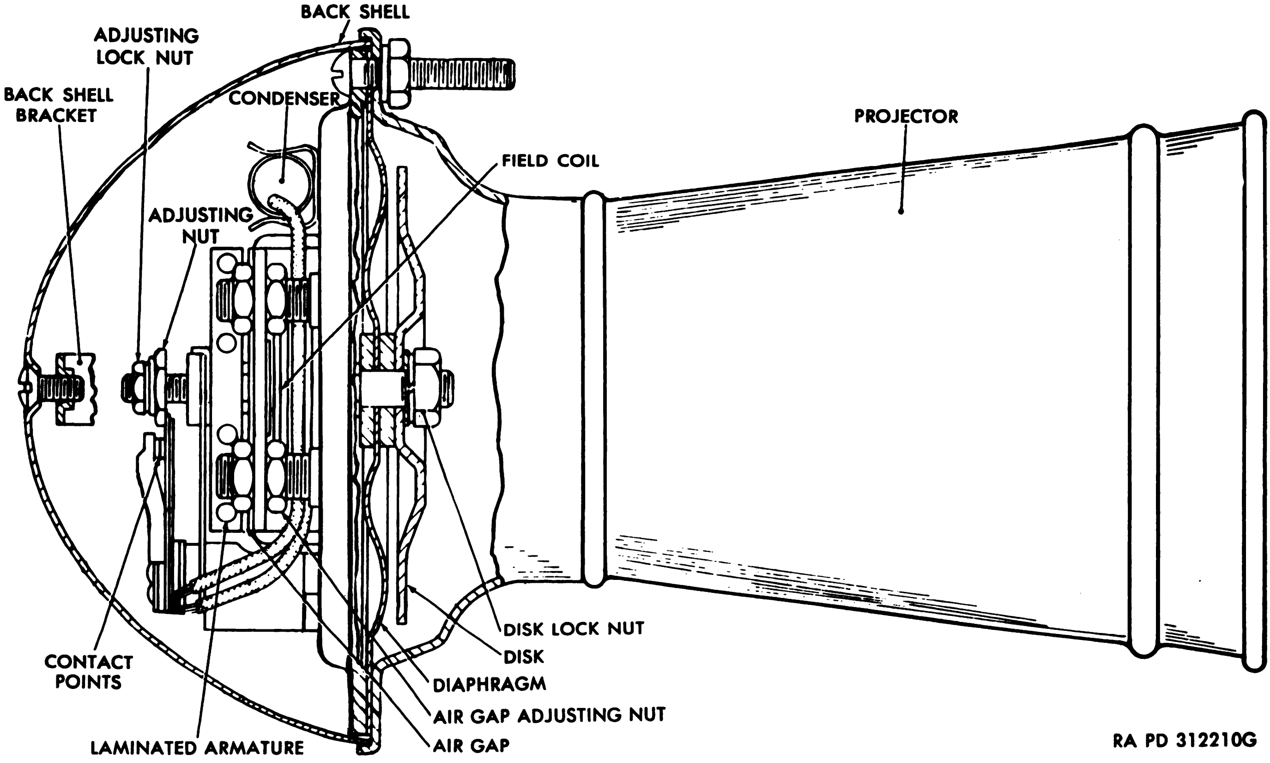


Figure 265. Electric horn (vibrator type)—cross sectional view.

magnetic strength varies. More current flows when the resistance is low (high engine temperature) and so a stronger magnetic field is created. As the engine temperature increases, the greater magnetic strength of the high-temperature coil attracts the armature and pointer to a point of balance between the two sides. The scale is calibrated to the pointer movement.

177. Horns

a. Description. The most common type of horn is the vibrator type in which the general principle of operation is the same as that of a vibrating coil. A vibrating diaphragm is operated by the coil which also operates the contacts that break the circuit. Magnetism from the coil pulls the diaphragm toward it when the contacts are closed. The contacts are then pulled open by the coil, reducing the magnetism and allowing the diaphragm to return to its normal position. When the contacts are closed again, a new surge of current induces magnetism in the coil and starts a second movement of the diaphragm. This cycle is repeated rapidly. The vibrations of the diaphragm within an air column produce the note of the horn. Typical horn construction is shown in figures 265 and 266.

b. Adjustment. Tone and volume adjustments are made by loosening the adjusting locknut and turning the adjusting nut. This very sensitive adjustment controls the current consumed by the horn. Increasing the current increases the volume. However, too much current will make the horn sputter and may lock the diaphragm.

c. Dual Horns. In dual horns, one horn with a low pitch is blended with another horn with a high pitch. These horns, although operated electrically, produce a sound closely resembling that of an air horn. The sound frequency of the low pitch horn is controlled by a long air column and that of the high pitch horn by a short air column. The air column is formed by the projector and by a spiral passage cast into the base of the horn. Inasmuch as the total current required by a horn is approximately 12 amperes, dual horns are operated by a relay switch and controlled by the horn button. The relay, when adjusted properly, should close at 4 volts; therefore, when the voltage available is less than 4 volts, the horns will not operate.

178. Accessories

a. Electric Motors. Accessories such as electric windshield wipers, heaters, and fans depend upon

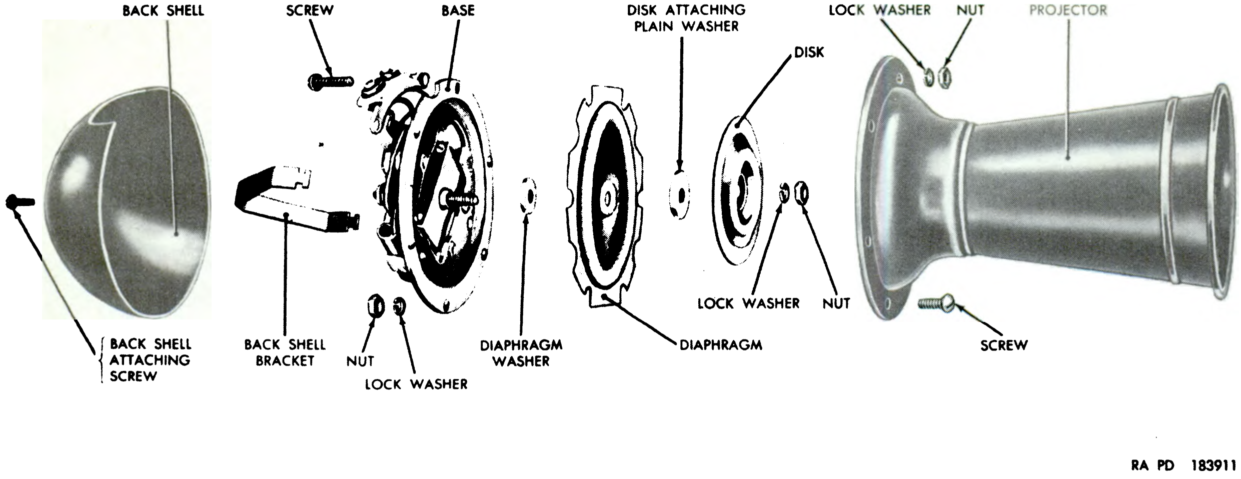

BACK SHELL
SCREW
BASE
DISK ATTACHING PLAIN WASHER
LOCK WASHER
NUT
PROJECTOR
DISK
BACK SHELL ATTACHING SCREW
BACK SHELL BRACKET
NUT
LOCK WASHER
DIAPHRAGM WASHER
DIAPHRAGM
LOCK WASHER
NUT
SCREW
RA PD 183911

Figure 266. Electric horn (vibrator type)—disassembled view.

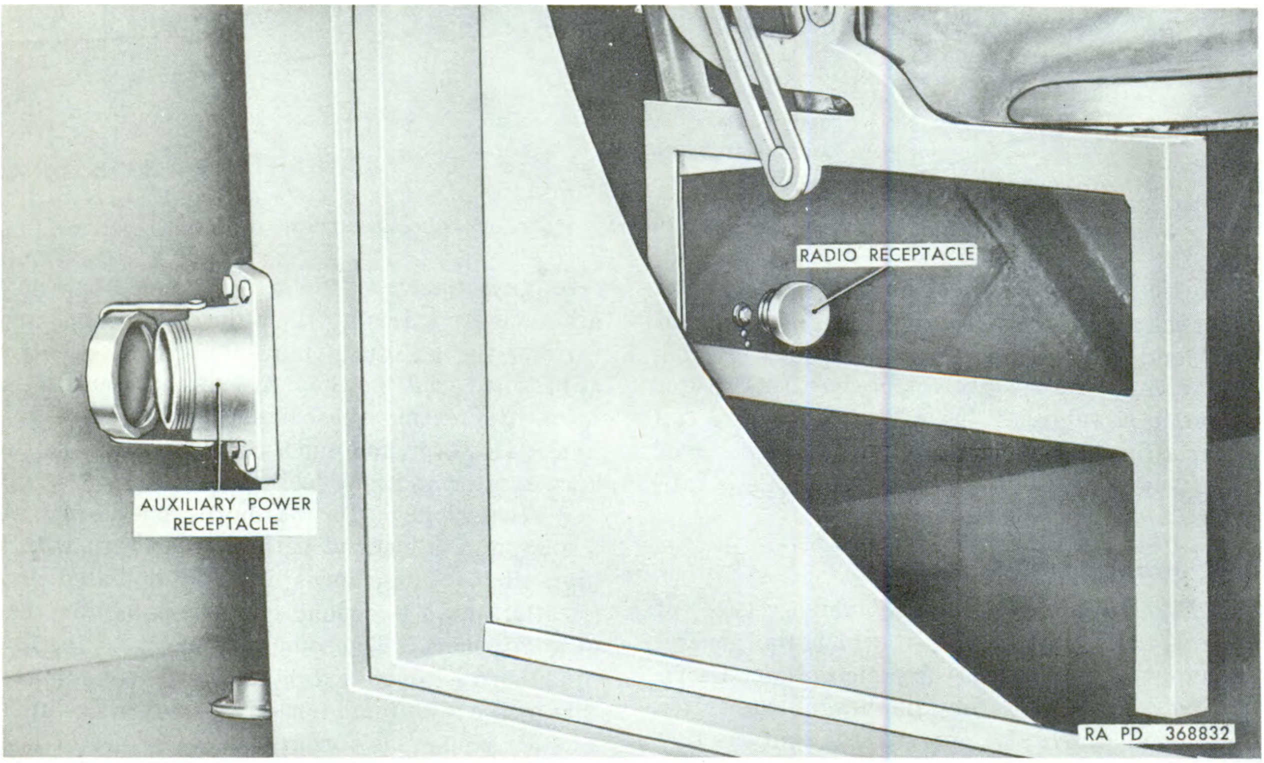

RADIO RECEPTACLE
AUXILIARY POWER RECEPTACLE
RA PD 368832

Figure 267. Location of auxiliary power receptacle at right-rear corner of cabbody.

small electric motors for their operation. These motors use about 45 watts. They should be connected to the ammeter so that any battery discharge required to run them is registered on the ammeter.

b. Windshield Wiper. The electric windshield wiper has suitable gearing placed on the motor shaft to provide the reciprocating motion required to operate the wipers. Heaters and fans have fan blades mounted on the motor shafts to circulate air within the car. The heater fan forces air through a heating element, similar to a radiator, which on most heaters is heated by the engine cooling water.

c. Auxiliary Power Receptacle. The auxiliary power receptacle usually is installed at the right-rear corner of the cab body, near the vehicle batteries (fig. 267). The receptacle has two insulated prongs, each connected by cable to one battery terminal. This means that the receptacle is wired in parallel with the battery. It is used to facilitate charging of the batteries from an external source or the connecting of additional electrical power from an external source to operate electrical components on the vehicle. The receptacle greatly simplifies these procedures since it is necessary only to unscrew the receptacle cap and plug in the connector to make the connections. No disconnecting and reconnecting of battery cable is necessary.

d. Air Pressure Gage. An air pressure gage (for use with vehicles equipped with air-hydraulic brake system), is employed to indicate air pressure in storage tanks. Gage face is marked in graduations of 30 psi from 0 to 120 psi. Full pressure in system is 100 psi. With engine running, air compressor governor cuts in at about 75 psi and compressor builds up pressure to full (100 psi). Do not drive vehicle until pressure is up to 60 psi. If, during operation, air pressure buzzer sounds (when below 60 psi), vehicle should be stopped and cause of air leakage corrected.

CHAPTER 12

RADIO INTERFERENCE AND SUPPRESSION

Section I. INTERFERENCE

179. Automotive Radio

While the supply and maintenance of radio equipment is properly a responsibility of the Signal Corps, its use by motor vehicle units for coordinating convoy movements in isolated areas must often be considered. For its source of power, transmitting and receiving equipment of this type depends upon the electrical system of the vehicle in which it is installed.

a. Installation. Installation of these units varies in different types and makes of equipment. In general, units of radio equipment should be mounted on brackets, panels, or metal members that are attached to the body or frame by welding or riveting. All paints, lacquers, or primers should be removed from all mounting surfaces that come in direct contact with the equipment and the surfaces should be tinned in order to insure the best possible ground. The units should be located so that all switches or controls are within easy access of the operator. All flexible control cables should be free of sharp bends. So far as possible, installation or removal of this type of equipment should be done by specialists of the Signal Corps who are trained in this type of work.

b. Power Requirements. Radio units require from 4 to 5 amperes for receivers and 12 to 16 amperes for large units and transmitters. In many instances, it will be found necessary to equip the vehicle with a larger generator with a regulator device to supply the additional current. All power leads from the vehicle electrical system should be of sufficient size to meet the current requirements and should be equipped with fuses or other overload protective devices. All leads should be as short as possible. High-voltage direct current is sometimes necessary, in which case a motor generator is required.

180. Interference

Any sparks created by the operation of electrical equipment (such as spark plugs, circuit breakers, coils, generators, regulators, magnetos, or distributor assemblies), by loose or dirty connections, or by chafing of metal to metal, may cause interference with radio reception of nearby radio receivers. In addition, such sparks will disclose the location of the vehicle to sensitive electrical detectors. Since the units of the electrical equipment are connected by a wire or a series of wires, as in an automotive ignition system, the wiring acts as an antenna to transmit the interference created by the spark into the air. The capacitive effect of the wires and the spark-producing unit causes the radiated energy to affect a wide band of frequencies on a radio receiver, with pronounced effects on certain frequencies.

181. Ignition Noises

a. Cause. When distributor breaker points are opened and closed by operation of engine, the ignition coil produces a high-voltage current which flows across the gap in the spark plug to cause ignition. The sparks at the plugs and those at the breaker points cause violent surges of current to flow in all wires of the circuit (fig. 268). Around each wire a magnetic field builds up and collapses with each make and break of the circuit. The rapidity with which these changes in the magnetic field are repeated is governed by the engine speed.

b. Recognition. The resultant noise in the receiver from breaker points, distributors, or spark plugs is recognized by clicking sounds which vary in rapidity and intensity with the speed of the engine.

182. Generator Noises

a. Causes. With the generator in operation, there is some sparking between the brushes and commutator segments. Generators in good mechanical condition may exhibit some sparking,

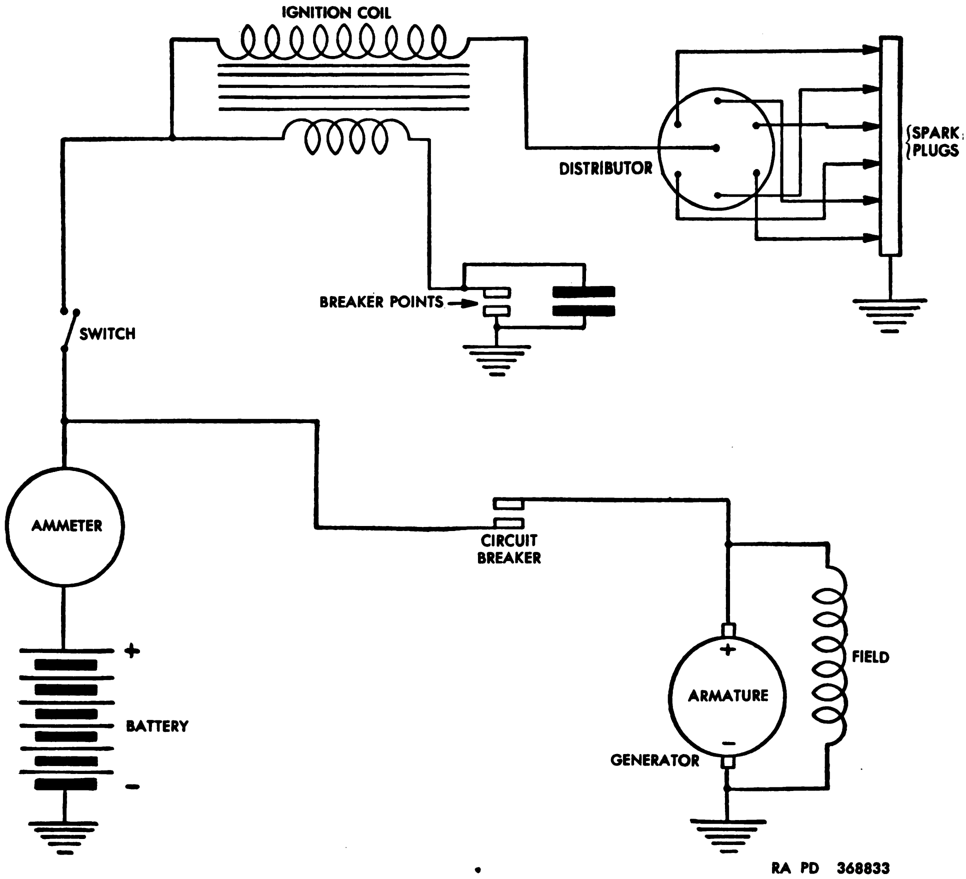


Figure 268. Typical battery ignition system.

but this usually is not severe enough to cause radio interference. This type of sparking is increased by any of the mechanical defects listed in (1) through (8) below.

(1) Brushes do not fit commutator.
(2) Brushes worn more than one-half original length.
(3) Incorrect brush spring tension.
(4) Collection of oil or carbon particles around commutator.
(5) Commutator worn out-of-round.
(6) Generator loaded in excess of rated capacity.
(7) Commutator segments burned or grooved.
(8) High insulation between segments of commutator.

b. Recognition. Sparking between the brushes and commutator segments may cause interference in nearby radio sets. This type of interference can be recognized by a roaring or whining noise that varies in pitch with the speed of the engine.

183. Body Noises

a. Causes. Body noises are produced by loose screws and bolts which allow various parts of the body to chafe against each other. This chafing produces static discharges which are a source of interference to radio receivers. Static charges caused by friction and induced charges from wiring on the vehicles are collected by the vehicle body. These charges are retained by poorly grounded sections of the body until they build up to a sufficient value to jump to any well-grounded part of the vehicle. Each discharge causes a spark of sufficient intensity to create interference in a radio receiver. These effects are produced only when the vehicle is in motion, or for a very short period after the vehicle is stopped.

b. Recognition. Looseness in the hood, brackets, and bolts can cause considerable noise in a receiver. This type of disturbance is intermittent, varies in value, and can be detected by a frying or snapping sound. It can be detected only when the vehicle is in motion; or, by moving the loose parts, it can be recognized by a scratching sound in a receiver.

Section II. SUPPRESSION

184. Description of Suppression Methods

a. General. Various methods are used to suppress radio interference caused by a vehicle. They are as follows:

Resistor-suppressors.
Capacitors.
Filters.
Bonding.
Shielding.

Application of one of the above methods is usually sufficient to adequately suppress the interference from any one source. However, in some instances it may be necessary to use a combination of these methods to obtain the desired amount of suppression.

b. Resistor-Suppressors. A resistor-suppressor consists of a short carbon rod of high resistance, protected by a plastic cover. Resistor-suppressors are connected in the high-tension wires at the spark plugs and distributor to reduce the intensity of surges and thus reduce interference from these sources. The resistance of the suppressors is high enough to control the surges but not high enough to affect the operation of the engine in any way. Some special-purpose spark plugs have a built-in resistor (fig. 269).

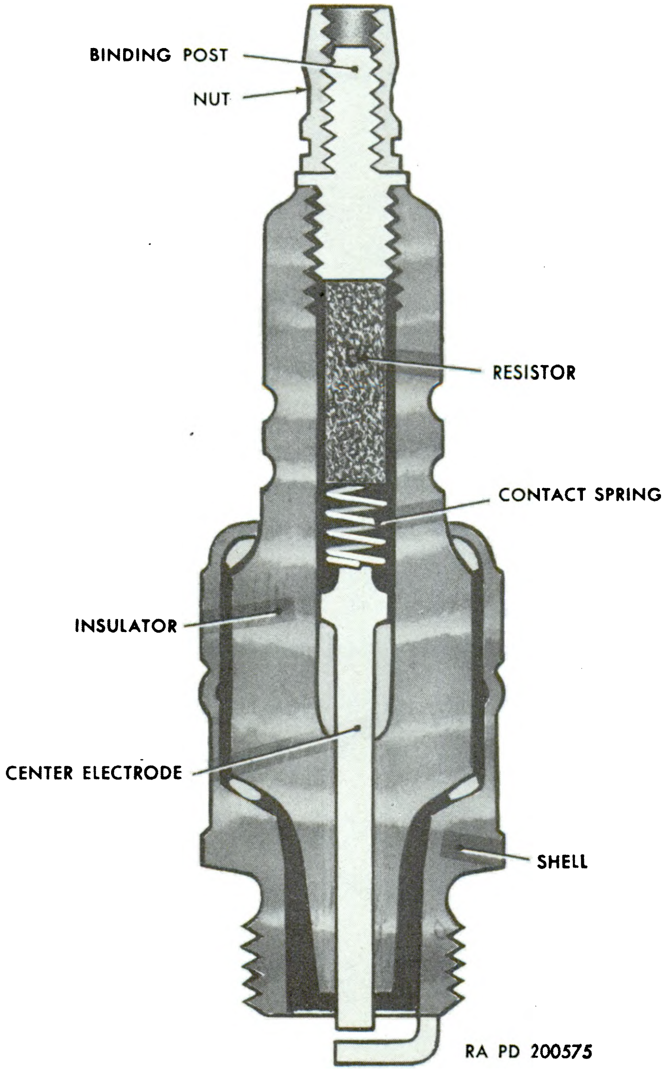


Figure 269. Spark plug with a built-in resistor.

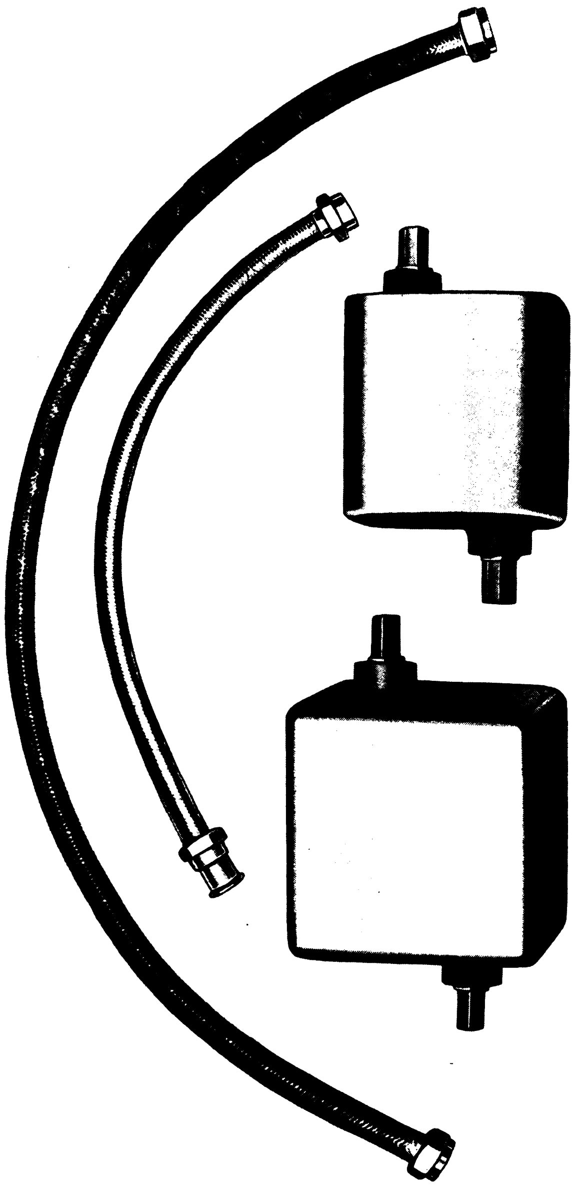


Figure 270. Radio interference suppression filters and cable shielding.

c. Capacitors. These are units of metal foils separated by paper insulation and protected by a metal case. The case is filled with an impregnating compound to keep the moisture out. A wire connected to one side of the capacitor is provided for connection to a circuit. The other side of the capacitor is connected internally to the case. Surges created in the wiring by sparks at the generator brushes, regulator, and gage contacts are not as strong as those produced by the high-tension ignition circuit because the voltage is low, but they are strong enough to cause interference in a radio set. Resistor-suppressors cannot be used in these circuits because their resistance would reduce the low-voltage current too much. However, capacitors may, because of their inherent capacitance, be used to dissipate these surges. They are attached to the circuit as near as possible to the point at which the spark occurs. The case of the capacitor is mounted on the metal frame of the unit causing interference, and the capacitor wire is connected to the terminal. A capacitor allows the interfering voltage to pass freely to ground (frame and body of vehicle), and at the same time prevents any loss of the useful direct current. Thus, the surges are conducted away from the wiring and cannot cause interference.

d. Filters. An assembly made of a closely wound coil of heavy wire and one or more capacitors mounted in a metal container is called a *filter* (fig. 270). The capacitors act in the same manner described in *c* above, and the coil of wire acts to block the interfering voltage from getting farther in the circuit. Filters are used in some generator, regulator, and low-tension ignition circuits.

e. Bonding. This term is applied to the method of electrically connecting individual metal sections to each other and to the frame or hull of the vehicle. Such bonding is necessary to provide an easy path for grounding static charges. Bonding is accomplished by internal-external toothed lockwashers, and by bond straps. The better the connection between metal parts, the greater is the effect in preventing interfering waves from being thrown off to affect radio reception.

f. Shielding. This term is applied to the method of covering with a metal shield (fig. 270) all wiring carrying interfering voltages or surges. Woven metal conduit is used where flexibility is required, while solid conduit is used elsewhere. Units causing interference, such as spark plugs, ignition coil, distributor, and regulator, are inclosed in metal boxes. This shielding does not reduce the intensity of the interfering surges, but prevents their radiation. While such shielding is effective in preventing the radiation of interfering waves, filters and capacitors are necessary to eliminate any interfering surges that would otherwise travel on the wires and affect the radio set through the power supply. Such filters and condensers are inclosed in metal shielding boxes provided with means of attachment to the conduit and shielding containing the connecting wires.

185. Typical Applications of Suppression Systems to Vehicles

a. Transport Vehicles—Ordinary Suppression System. The system found on most vehicles consists of the items described in (1) through (7) below.

(1) Resistor-suppressors are used in each high-tension lead from distributor to spark plugs. The suppressors are usually of a type that will slip over the terminal of the plug. The lead is screwed directly into the suppressor, thus locating the suppressor as close as possible to the spark gap in the plug.

(2) A resistor-suppressor is used in the high-tension lead from distributor to coil. This suppressor is placed in the lead as close as possible to the distributor. Usually, it will be found about an inch or two away from the distributor.

(3) A filter is placed in the lead from the ignition coil to the ignition switch. This filter is mounted on the firewall where the lead goes through to the switch. Thus, the exposed lead between the filter and firewall is kept as short as possible. In later production vehicles, this filter is replaced by a capacitor which is usually mounted on or near the coil, with its lead connected to the switch side of the ignition coil primary circuit.

(4) Filters are used in regulator circuits. One is usually connected between the battery terminal of the regulator and the ammeter, one is connected in the generator armature lead, and one is sometimes connected in the field lead between the generator and regulator. These filters are mounted on the firewall in such a position that the exposed leads leaving the filter are as short as possible. On certain vehicles, capacitors (usually 0.1 mfd capacity) may be found at these points, mounted on the firewall, with the leads connected to the battery and generator armature terminals. A 0.01 mfd capacitor is sometimes applied with its lead connected to the field terminal of the regulator.

(5) A capacitor is mounted on the generator with its lead connected to the output terminal. Capacitors are used on certain lighting circuits, either mounted on the firewall or close to any junction point. The lead is connected to the circuit that may be carrying radio interference.

(6) Bonding straps will usually be found at the places described in (*a*) through (*f*) below. There may be others, also.

  (*a*) From hood to firewall.

  (*b*) From hood top panel to hood side panel.

  (*c*) From overhead valve covers to firewall.

  (*d*) From engine block to frame.

  (*e*) From fenders and fender skirts to frame.

  (*f*) From radiator brush guard to frame.

(7) Bonding by means of internal-external tooth lockwashers will usually be found at the places described in (*a*) through (*f*) below.

  (*a*) Under head of side panel mounting screws.

  (*b*) Hood holddown locks or latches.

  (*c*) At gage sending unit.

  (*d*) Under head of radiator grille mounting screws.

  (*e*) Under head of fender mounting screws.

  (*f*) Under head of any bolt or screw securing a separate section of metal that will help to form a shield in the vicinity of the engine compartment.

b. Transport Vehicles—Completely Shielded Suppression System. A few vehicles have a completely shielded system of suppressing, and in such cases usually only one filter is used. It is mounted in a metal box close to the regulator (it may be on the cab side of the firewall). A capacitor will be found mounted on the generator, in a round metal shielding case. In most cases, the only bond is between the engine and the frame.

c. Tanks and Armored Cars. The resistor-suppressor system used on tanks with in-line engines and on most armored cars is basically the same as that used on transport vehicles described in *a* above. Usually, there will be fewer bonds and toothed lockwashers and more capacitors. Less bonds and washers are needed because of the heavy, bolted, or welded construction of the hull or body. Resistor-suppressors, filters, and capacitors are used in the same circuits as in the transport vehicles. More capacitors will be used to bypass the interfering surges from such accessories as Auto-pulse fuel pump, electric gages, windshield wipers, traversing motors, auxiliary generators, and similar items. The capacitors are always mounted close to the device causing interference, with the lead connected to the "hot" side of the supply line. The complete shielding system is used on most tanks having radial engines and on some armored cars.

(1) In tanks, all wiring is inclosed in flexible metal conduit or solid metal conduit. Very little bonding is necessary with this system. In most cases, only the engine is bonded to the support or hull. Control devices consisting of metal rods or tubing extending from crew compartment to engine compartment may be bonded at the points they enter the crew compartment.

(*a*) Usually one filter is used, inclosed in a shielding box. It is always mounted close to the regulator and the battery.

(*b*) Capacitors are used on the electrical devices in the turret. They will be found at the brushes of the traversing motor, generator, and in the circuits of the stabilizer control switch box.

(2) In armored scout cars and gun motor carriages that have the completely shielded system, all high-tension, primary ignition, and charging circuit wiring is shielded with flexible metal conduit which is grounded every 2 feet with clips and internal-external tooth washers. The distributor, ignition coil, and regulator are shielded.

(*a*) Filters may or may not be used. If one is used, it will be mounted close to the regulator on the firewall.

(*b*) A capacitor is mounted on the generator.

(*c*) Usually, the only bond is the one from engine to frame. Both sides of the engine are generally bonded.

PART FOUR

POWER TRAINS

CHAPTER 13

INTRODUCTION TO POWER TRAINS

186. Purpose

The purpose of the power train is to transmit the power of the engine to the wheels and accessory equipment, such as winches. In a simple situation, a set of gears or a chain could perform this task, but automotive vehicles are not usually designed for such simple operating conditions. They are designed to have great pulling power, to move at high speeds, to travel in reverse as well as forward, and to operate on rough ground as well as on smooth roads. To meet these widely varying demands, a number of units have been added. These include clutches, transmissions, auxiliary transmissions, transfer cases, propeller shafts, universal joints, final drives, differentials, live axles, devices for resisting drive torques and thrust, and the bearings used therein.

187. Gears

a. General. Since gears play an important part in power trains, let us discuss gear principles as well as various types of gears used in power trains. Gears are used to transmit rotary motion from one shaft to another. Sometimes the shafts are parallel to each other, at other times they are at an angle. The gearing is selected to fit the application and provide the desired drive ratio (ratio of revolutions per minute, rpm) between the driving and driven shafts.

b. Spur Gears.

(1) *Gear ratio.* Two meshing spur gears are shown in figure 271. Both gears have the same number of teeth and are of the same diameter. Thus, both turn at the same speed. The gear ratio is therefore 1 : 1. Figure 272 shows two meshing spur gears, one with 12 teeth and the other with 24 teeth. The smaller gear will revolve twice as fast as the larger gear. The gear ratio between the two, when the smaller gear drives, is 24 : 12, or 2 : 1. Thus, the gear ratio between two meshing gears is the relative speed, or rpm, that they turn.

(2) *Mechanical advantage.* The use of a lever to move heavy objects is well-known. When a box is too heavy to be lifted by hand, a crowbar or lever can be used to lift it, as shown in figure 273. With the lever placed as shown, only half as much force is required on the lever to raise the box. Suppose that a lifting force of 200 pounds is required to raise

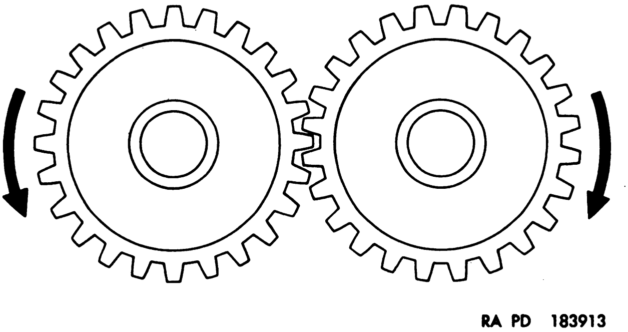

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Figure 271. Meshing gears with 1 : 1 gear ratio.

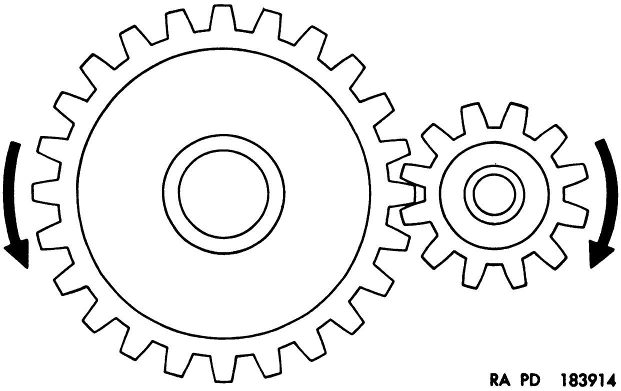
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Figure 272. Meshing gears with 2 : 1 gear ratio.

the end of the box. With the lever arranged as shown, only a 100-pound downward push is needed on the lever. The farther out on the lever the land is put (away from the pivoting point, or fulcrum), the less downward push is required. But also, the farther the hand must move to raise the box. The mechanical advantage of the lever is the ratio between the two distances from the fulcrum. In the example shown, the mechanical advantage is 2 : 1.

(3) *Mechanical advantage in gears.* A rough comparison between mechanical advantage in levers and mechanical advantage in gears can be made. Such a comparison is shown at the bottom of figure 273. One end of the lever moves twice as far as the other. When two gears are meshed and one gear has twice as many teeth as the other, the smaller gear will rotate twice for each revolution of the larger gear. In other words, the mechanical advantage between the two gears would be 1 : 2 when the larger gear drove the smaller gear. If the smaller gear drove the larger gear, the mechanical advantage would be 2 : 1 since the smaller gear would have to exert half the force for twice the distance.

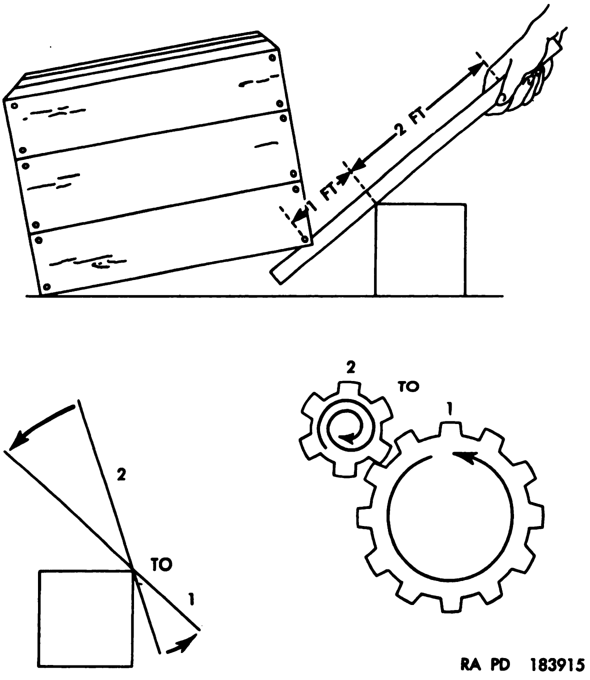
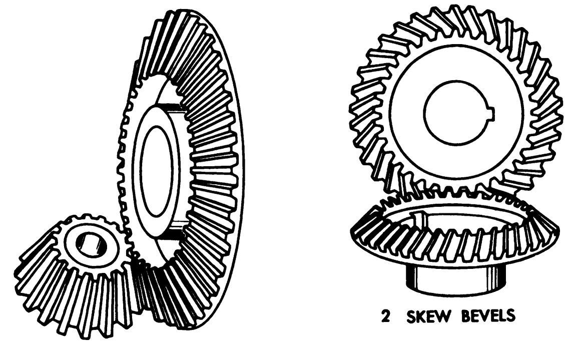


Figure 273. Illustrating mechanical advantage of gearing.

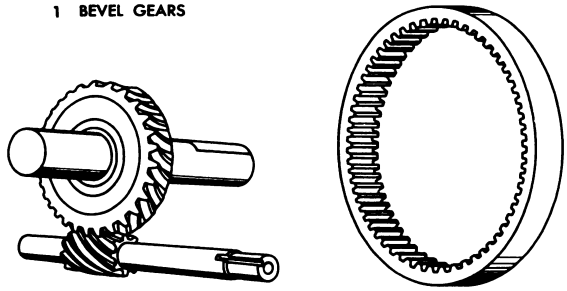
c. Torque Ratios in Gears. Torque has been defined as a twisting, or turning, effort (par. 12 *f*). When one gear drives the other, it turns the other by the application of torque. The torque ratio between two meshing gears varies with the mechanical advantage, that is, with the gear ratio of the driving to the driven gear. When a small gear drives a larger gear, for example, the speed is reduced but the torque delivered by the larger gear is increased. Thus, when a 12-tooth gear drives a 24-tooth gear, torque is doubled; that is, the torque of the large gear is twice that of the small gear. On the other hand, when the larger gear drives the smaller gear, the torque is reduced while the speed is increased. To start an automotive vehicle moving, a great deal of tractive effort or torque must be applied to the driving wheels or drive sprockets. This may be accomplished by using a series of gears, or a gear train, which greatly reduces the speed and thereby greatly increases the torque between the engine and driving wheel or sprocket. A common arrangement in passenger cars permits a gear reduction, in first (or low) gear, of 12 : 1 between the engine and rear wheels. This means the engine crankshaft must turn 12 times to turn the rear wheels once. This speed reduction results in a torque increase. Ignoring friction, the torque increase would be twelvefold. That is, if the torque at the crankshaft were 100 pound-feet, then the torque at the rear axles would be 1,200 pound-feet. In large trucks and heavy military vehicles the torque increase (or torque multiplication) may be much greater than 12 : 1.

d. Types of Gears. Numerous types of gearing are used in automotive applications. In addition to the very common spur gears shown in figures 271 and 272, several other types are shown in figure 274. Bevel gears are used to change directions in the power train. The two shafts are usually at right angles to each other, but not necessarily so. Worm gearing is not often used in power trains, but a modified worm gear is used in many steering systems; the worm gear is assembled on the lower end of the steering column. The internal gear has gear teeth facing in toward its center rather than out. It is used with a gear in which the teeth face out.



1 BEVEL GEARS

2 SKEW BEVELS



3 WORM GEAR

4 INTERNAL GEAR

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Figure 274. Various types of gearing.

e. Planetary Gear Systems.

(1) The planetary gear system (fig. 275) consists of three rotating members, the internal gear (or ring gear), the sun gear, and the planet pinion set, consisting of the planet pinions and the planet-pinion carrier, or cage. The reason the system is called a planetary gear system is that the planet gears rotate and at the same time revolve around the sun gear, just as the planets in our solar system rotate and also revolve around the sun. In the planetary gear system the planet gears are assembled on shafts in a planet carrier or cage. Arrangements can be made to put power into any of the three rotating members and, at the same time, hold other members so that the gear ratio through the system can be increased or decreased. In addition, by the proper arrangement of turning and holding, the system can reverse rotation.

(2) The chart in figure 276 shows the six conditions that can result in the planetary gear system from turning or holding the various members. For example, the column under Condition 1 shows that holding the sun gear while turning the pinion cage causes the internal gear to turn faster than the pinion cage. When the pinion cage is turned, the pinions must walk around the sun gear because they are meshed with the sun gear. The pinions are also meshed with the internal gear and as they walk around the sun gear, and also rotate on their shafts, they force the internal gear to rotate. The rotation might be said to come from two sources, the rotation of the pinions on their shafts and the rotary motion of the pinions as they are carried around by the pinion cage.

(3) The other conditions listed in the chart (fig. 276) are not all used in automotive power trains, but they should be studied for a full understanding of the action of the planetary gear system. If the sun gear is held and the internal gear turned, then the pinion cage will turn, but more slowly than the internal gear. If the sun gear is turned and the internal gear held, the pinion cage will turn more slowly than the sun gear. On the other hand, if the internal gear is turned and the pinion cage held, the sun gear will turn faster than the internal gear, but in a *reverse direction.* The fifth condition results if the internal gear is held and the pinion cage turned; this causes the sun gear to turn faster than the pinion cage.

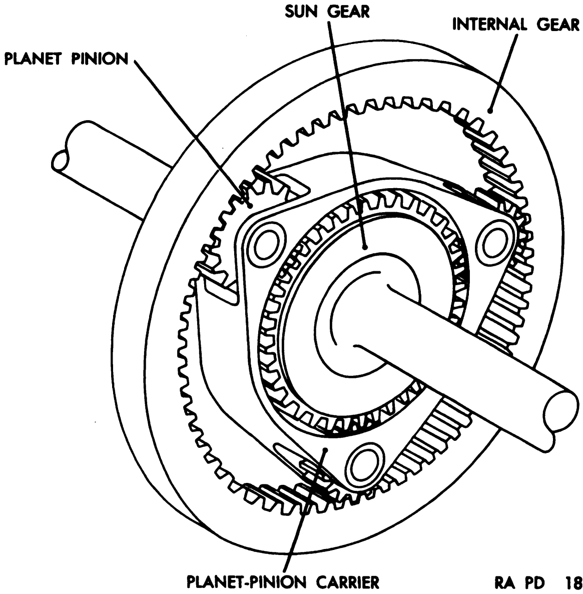

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Figure 275. Planetary gear system.

CONDITION	1	2	3	4	5	6
SUN GEAR	H	H	T	IR	I	T
PINION CAGE	T	L	L	H	T	H
INTERNAL GEAR	I	T	H	T	H	LR

H—HOLD
T—TURN
R—REVERSE
I—INCREASE OF SPEED
L—REDUCTION OF SPEED

RA PD 183918

Figure 276. Chart relating various actions in planetary systems.

The sixth condition is a common one since, by its use, reverse and gear reduction can be accomplished at the same time. The sun gear is turned while the pinion cage is held. This causes the internal gear to turn more slowly than the sun gear and in a reverse direction.

188. Bearings

a. General. Essentially, a bearing is a support for a load. In automotive applications, bearings support moving parts, most of which are rotating parts. Not only do the bearings provide support, but they also serve to reduce the friction between the moving parts. Friction is discussed in paragraph 13*a*.

b. Sliding Surface Bearings.

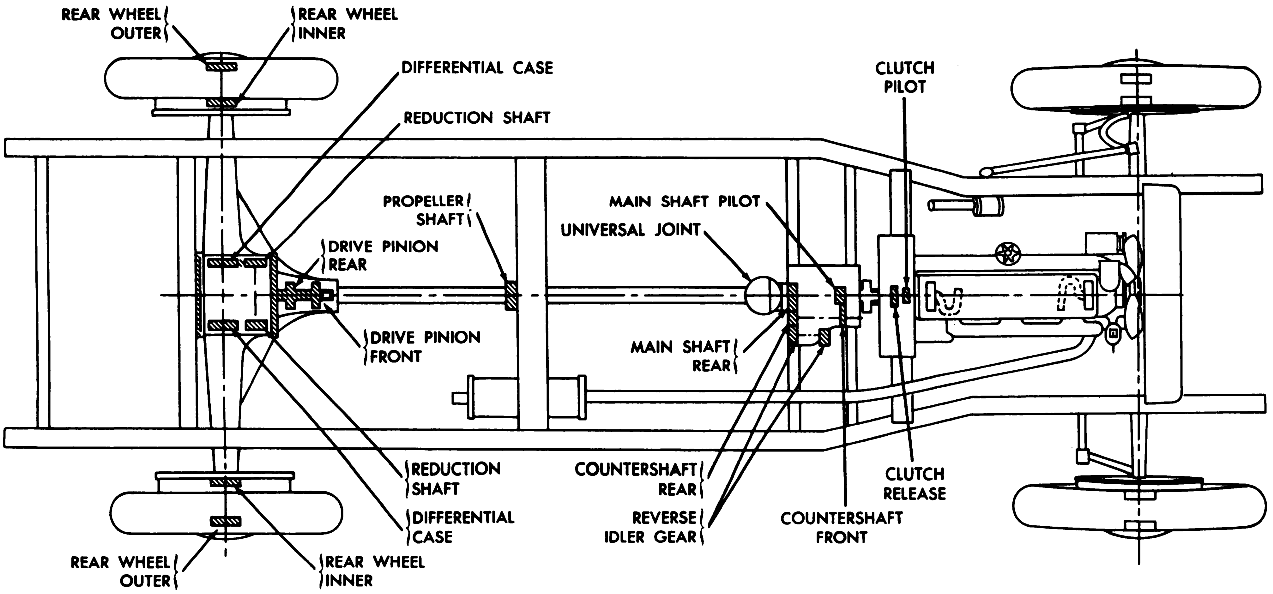
(1) These include bearings for rotating parts and for parts that merely slide over each other without turning. Most of the bearings of the mechanisms described in this section are for rotating parts. However, two examples of bearings for parts that do not rotate relative to each other are the shifter shafts in transmissions, which merely slide endwise in holes in the case, and the slip joints of propeller shafts.

(2) The simplest type of sliding surface bearing applied to a rotating part is one in which an accurately finished shaft, or journal, rotates in an accurately finished hole without any bushing, the two being separated by an oil film. Such bearings may be used for differential pinions; the holes are in the rotating pinions which turn on the stationary differential spider or cross pin. Such bearings are usually known as *plain bearings* and are used only for low speeds or light duty or both.

(3) Probably the next simplest plain bearing, also of the sliding-surface type, is the bushing that is replaceable when worn. A bushing is usually of bronze or similar relatively soft material and is pressed into a hole and reamed to fit, forming a lining in which a journal rotates. Plain bushings are suitable for radial loads only bronze bushings were formerly used to a considerable extent in automotive power transmission systems but have been almost entirely superseded by antifriction bearings (ball, roller, or needle bearings). Bronze bushings are used extensively for piston pin bushings in internal combustion engines.

c. Ball and Roller Bearings.

(1) *General.* These bearings are used throughout automotive power transmission systems. The usual locations of antifriction bearings in a truck chassis are shown in figure 277. They are commonly known as *antifriction bearings*, since friction in them is largely eliminated because they depend upon rolling contact rather than sliding contacts. Ball bearings often are referred to as having point contact between balls and raceways; in the same sense, roller bearings are said to have line contact between rollers and races. These are merely descriptive terms, however, since the elastic deformation occurring under load results in substantial areas of contact in either type. The starting friction of ball and roller bearings is but slightly greater than their running friction, an important advantage in machinery that is required to start frequently under load. They can also sustain high overloads for short periods without failure. Ordinarily, a ball or roller bearing does not fail suddenly, but gives warning by a gradual decrease in smoothness of running; whereas, the plain bearing is subject to an accelerated type of failure which often results in seizure, making it necessary to take the machine out of operation for immediate repairs.


REAR WHEEL OUTER
REAR WHEEL INNER
DIFFERENTIAL CASE
REDUCTION SHAFT
PROPELLER SHAFT
DRIVE PINION REAR
DRIVE PINION FRONT
UNIVERSAL JOINT
MAIN SHAFT PILOT
MAIN SHAFT REAR
CLUTCH PILOT
REDUCTION SHAFT
DIFFERENTIAL CASE
COUNTERSHAFT REAR
REVERSE IDLER GEAR
COUNTERSHAFT FRONT
CLUTCH RELEASE
REAR WHEEL OUTER
REAR WHEEL INNER

RA PD 183919

Figure 277. Locations of antifriction bearings in a truck power train.

(2) *Types of ball bearings.* A ball bearing consists essentially of a grooved inner race and outer race with a number of balls spaced by a suitable cage or retainer between them. They are made with either a single or double row of balls. Ball bearings for various purposes differ considerably in the details of their construction but are of three general types—*radial*, *thrust*, and *angular*. These terms are descriptive of the direction at which the load is applied to the bearing and the angle of contact between the balls and races designed to resist that load. A single-row radial ball bearing is shown in figure 278. This bearing has radial contact between balls and races, and is designed primarily to resist radial loads but also provides for lengthwise stability where moderate lengthwise displacement is permissible. It is suitable for usual combined radial and thrust loads and for high speeds. The double-row radial ball bearing shown in figure 279 is suitable for heavy combined radial and thrust loads, medium speed, and close control of endwise movement under reversing thrust. Single-row, angular-contact ball bearings, such as those shown in figure 280, have substantial thrust capacity and provide rigid lengthwise support in one direction only. Also available are double-row, angular-contact bearings which have high combined load capacity together with rigid lengthwise support in both directions. Thrust bearings of the so-called flat type, such as those

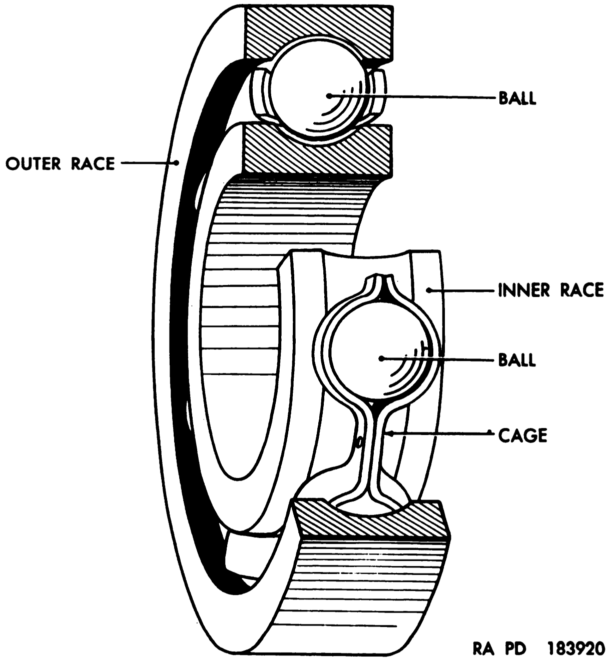

BALL
OUTER RACE
INNER RACE
BALL
CAGE

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Figure 278. Single-row radial ball bearing.

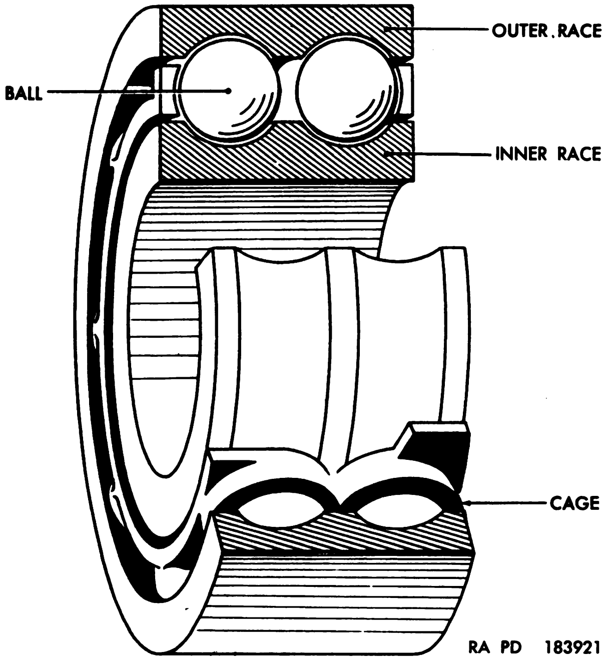


Figure 279. Double-row radial ball bearing.

shown in figure 281, have a contact angle of 90°, or a load line between ball and race that is parallel with the axis of the shaft. The small-bore race is secured to the shaft and the large-bore race is supported by the housing. Thrust in one direction presses the races and balls together; thrust in the other direction separates them. Therefore, this type is essentially a one-direction thrust bearing. Thrust in both directions necessitates the use of duplicate units or a bearing of the double-direction thrust type. Such bearings are suitable for limited speeds and minimum lengthwise displacement.

(3) *Types of roller bearings.*

(*a*) As in the case of ball bearings, the details, of construction of roller bearings vary considerably for different applications. Like ball bearings, they are designed for radial, thrust, and combined loads. Roller bearings, which have greater contact area than ball bearings, are used for heavy-duty applications.

(*b*) Cylindrical, or straight, roller bearings are bearings in which the outer races, rollers, and inner races are all cylindrical. Rollers are usually solid as shown in figure 282, and the rollers are guided by flanges on one or both races. If both races are flanged, the bearing has some ability to resist end thrust, otherwise it is good for radial loads only. One manufacturer uses rollers formed by helically winding

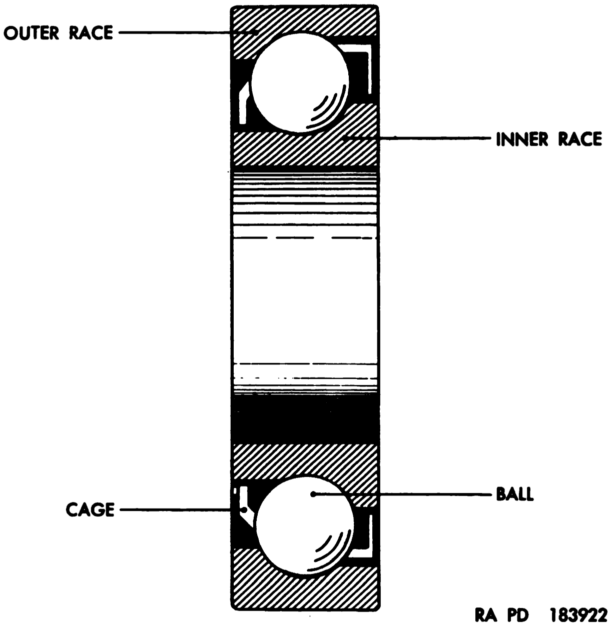


Figure 280. Single-row angular-contact ball bearing.

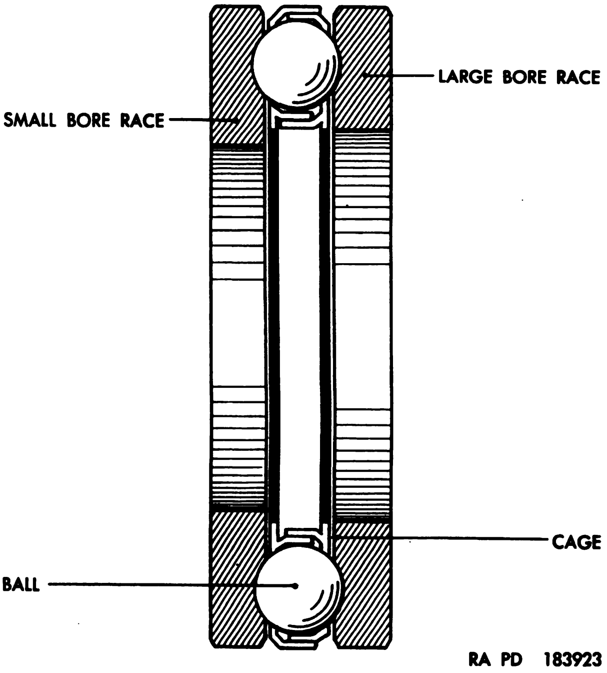


Figure 281. Flat-type thrust ball bearing.

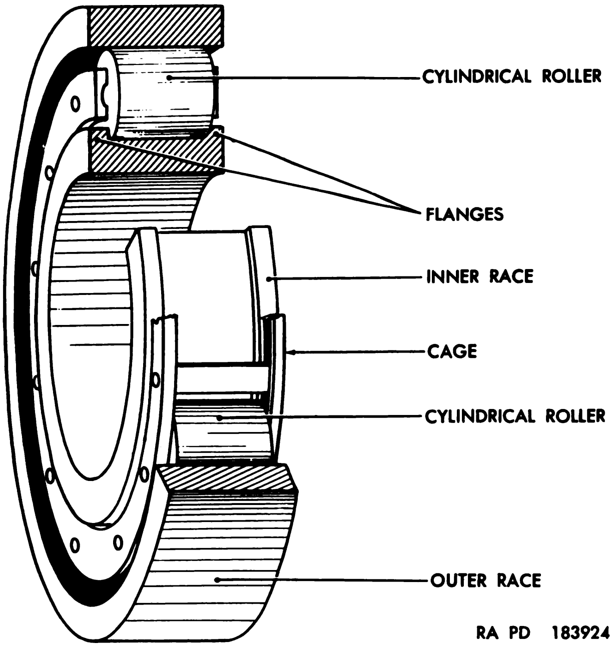


Figure 282. Cylindrical roller bearing with solid rollers.

strips of alloy steel into hollow cylinders which are then heat-treated and ground to size. This construction imparts some flexibility to the rollers and enables them to adjust themselves to small inaccuracies. Rollers wound right and left hand are assembled alternately in the bearing and held in proper alinement by a cage retainer. These bearings are made with solid inner and outer races, with solid outer race and no inner race, and with a split outer race and no inner race. *Needle* bearings (or *quill* bearings, as they are sometimes called) are cylindrical roller bearings in which the diameter of the roller is not over one-eighth the roller length. Separate outer and inner races may be used, or the inner race may be the shaft and the outer race integral with the housing. No spacing cage is ordinarily used; the rollers are merely constrained against endwise movement. Needle bearings are suitable for radial loads only. These bearings are used where a high load-carrying capacity is required in a small space. Needle bearings are used in many universal joints.

(*c*) Tapered roller bearings, such as are shown in figure 283, are used extensively in automotive power transmission systems, especially for the more heavily loaded rotating members. The rolling members and raceways of the tapered roller bearings are constructed on the elements of a cone, so that lines that coincide with the contacting surfaces of rollers and races all meet at a common point on the axis of the bearing as shown at the bottom of figure 283. True rolling contact is thus obtained. The essential parts are an inner race or cone, an outer race or cup, tapered rollers, and a cage or roller retainer. These bearings are suitable for heavy duty, and can withstand radial loads and thrust loads in one direction or a combination of both. Such bearings are also available with double and quadruple rows of tapered rollers. Flat thrust bearings having tapered rollers, suitable for thrust loads only, are also available.

d. Lubrication.

(1) A basic requirement of ball and roller bearing lubrication is to protect the highly finished surfaces from corrosion. The

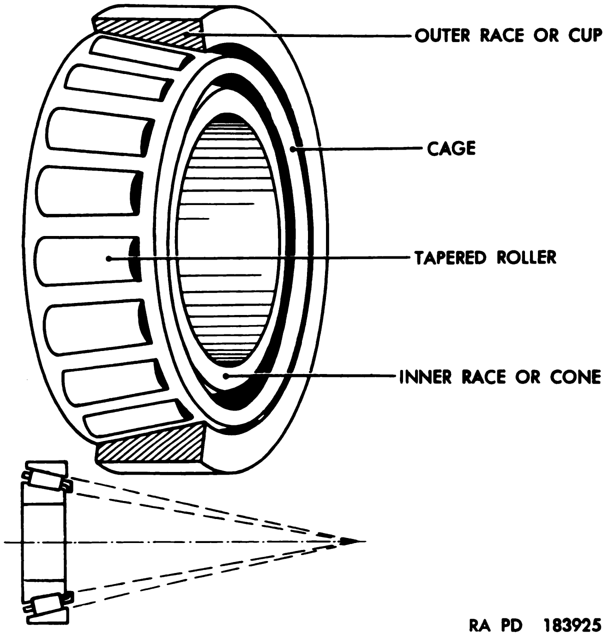


Figure 283. Tapered roller bearing, showing principle of bearing at bottom.

supporting surfaces of the cage, or retainer, essentially are plain bearings and require an oil film. A small quantity of oil or grease will lubricate a bearing if it is evenly distributed. An excess quantity of lubricant is undesirable because it will cause the bearing to heat and will aggravate leakage from the bearing housing. Operating temperature is the controlling factor in selecting the proper grade of lubricant. Load, speed, and weather conditions directly affect this temperature, as does the particular type of bearing and the shaft inclosures.

(2) The antifriction bearings in automotive power transmission systems are not lubricated as separate units but as parts of assemblies such as clutches, transmissions, universal joints, transfer cases, rear axles, etc. If these assemblies are lubricated in accordance with the specifications as set forth in the applicable technical manual, and with the lubricant prescribed for each, the bearing requirements will be satisfied.

189. Basic Power Trains—Wheeled Vehicles

The common elements of the power transmission system assemmbled in typical vehicles are shown in figures 284 and 285. Reading from the engine to the wheels, the main units of the power train are described in *a* through *i* below.

a. Clutch. By means of the clutch the operator can disconnect the engine from the remainder of the power train. This is essential for starting the engine, for allowing the vehicle to stand motionless while the engine is running, for gradual engagements of the engine to the power train, and for allowing gear ratios to be changed to meet varying road conditions.

b. Transmission. An internal combustion engine cannot develop appreciable torque at low speeds, and it develops maximum torque only at one speed. The chankshaft of an engine must always rotate in the same direction. For these reasons, the transmission is necessary in automotive vehicles. The transmission provides the mechanical advantage that enables the engine to propel the vehicle under adverse conditions of load. It also provides the driver with a selection of vehicle speeds while the engine is held at speeds within the effective torque range, and it allows disengaging and reversing the flow of power from the engine to the wheels.

c. Transfer Assembly. This assembly is an auxiliary gear train on all-wheel-drive vehicles. It permits the power to be divided and transferred to both front and rear propeller shafts, and to the propeller shaft on amphibious vehicles. It also provides a means of lowering or displacing the power train sufficiently to permit the front propeller shaft to clear the crankcase of the engine.

d. Universal Joints. It is necessary to provide flexibility in the power train if springs are to be used on the vehicle. As load is increased or decreased, and as the vehicle travels over uneven surfaces, the angle between the engine crankshaft axis and a line to the axle will change. This flexibility is provided by the use of universal joints which permit transfer of torque at an angle.

e. Slip Joints. As the load is changed, and as the vehicle travels over uneven ground, the distance from unit to unit in the power train varies. Slip joints provide for this variation.

f. Propeller Shaft. This device carries the torque from one place to another; from the transfer case to the differential, for example.

g. Final Drive. This device transmits the power flow from the propeller shaft to the differential and, at the same time, provides a further gear reduction.

h. Differential. When a vehicle is driven around a curve, the outer wheels travel faster, as well as farther, than the inner wheels, The differential permits this difference in rotational speed of the axles.

i. Types of Drive. When a turning force, or torque, is exerted through the final drive and axle shafts to turn the driving wheels, there is an equal and opposite torque, or reaction, tending to turn the axle housing in the opposite direction. The tractive effort of the wheels on the road, which propels the vehicle forward or backward, is also exerted on the axle housing. Some member or members must be provided, therefore, to prevent the axle housing from turning, and to transmit the forward or backward thrust of the driving wheels to the frame of the vehicle. Four methods, and at least one combination of these

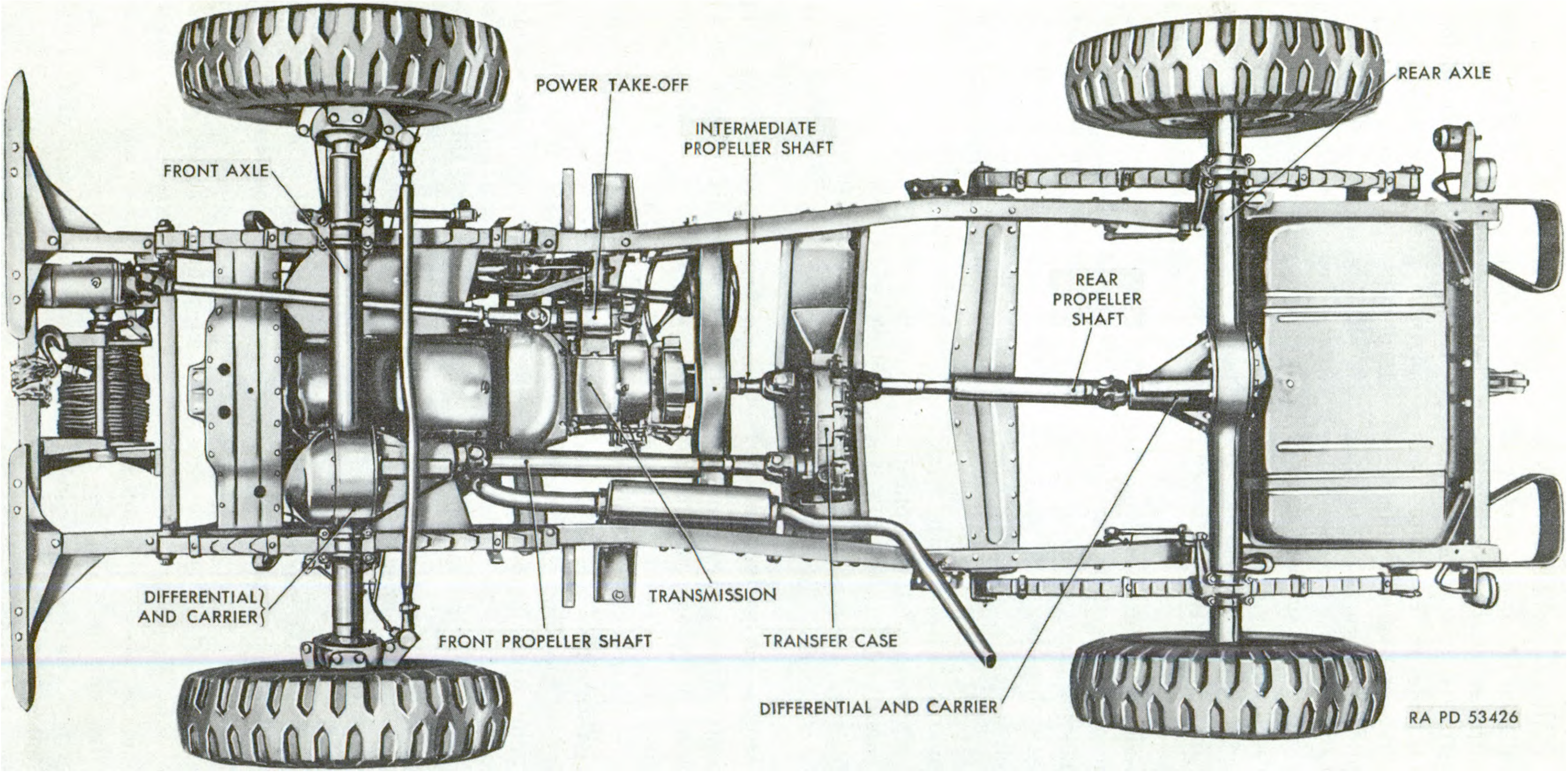

POWER TAKE-OFF
INTERMEDIATE PROPELLER SHAFT
FRONT AXLE
REAR AXLE
REAR PROPELLER SHAFT
DIFFERENTIAL AND CARRIER
TRANSMISSION
FRONT PROPELLER SHAFT
TRANSFER CASE
DIFFERENTIAL AND CARRIER
RA PD 53426

Figure 284. Power transmission system in 4 x 4 wheeled vehicle.

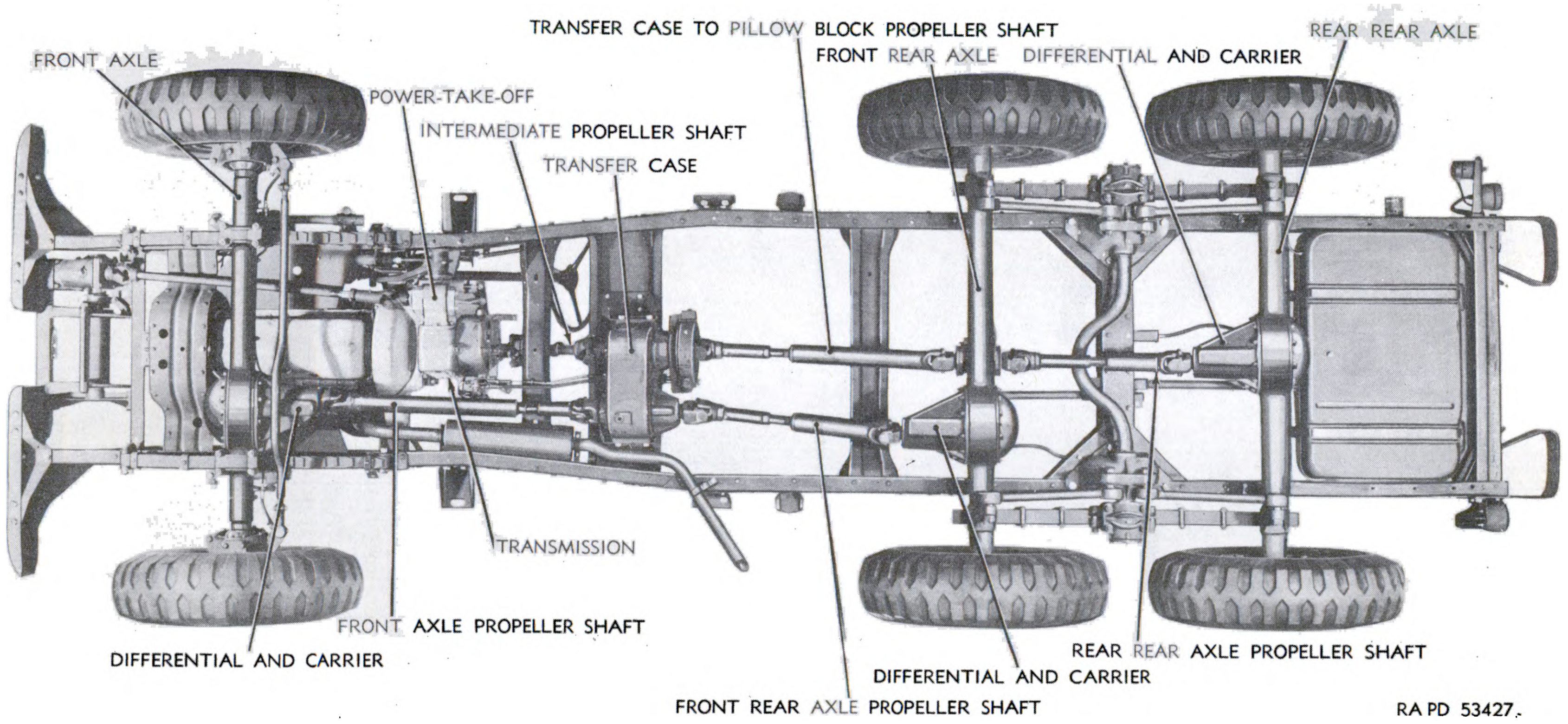
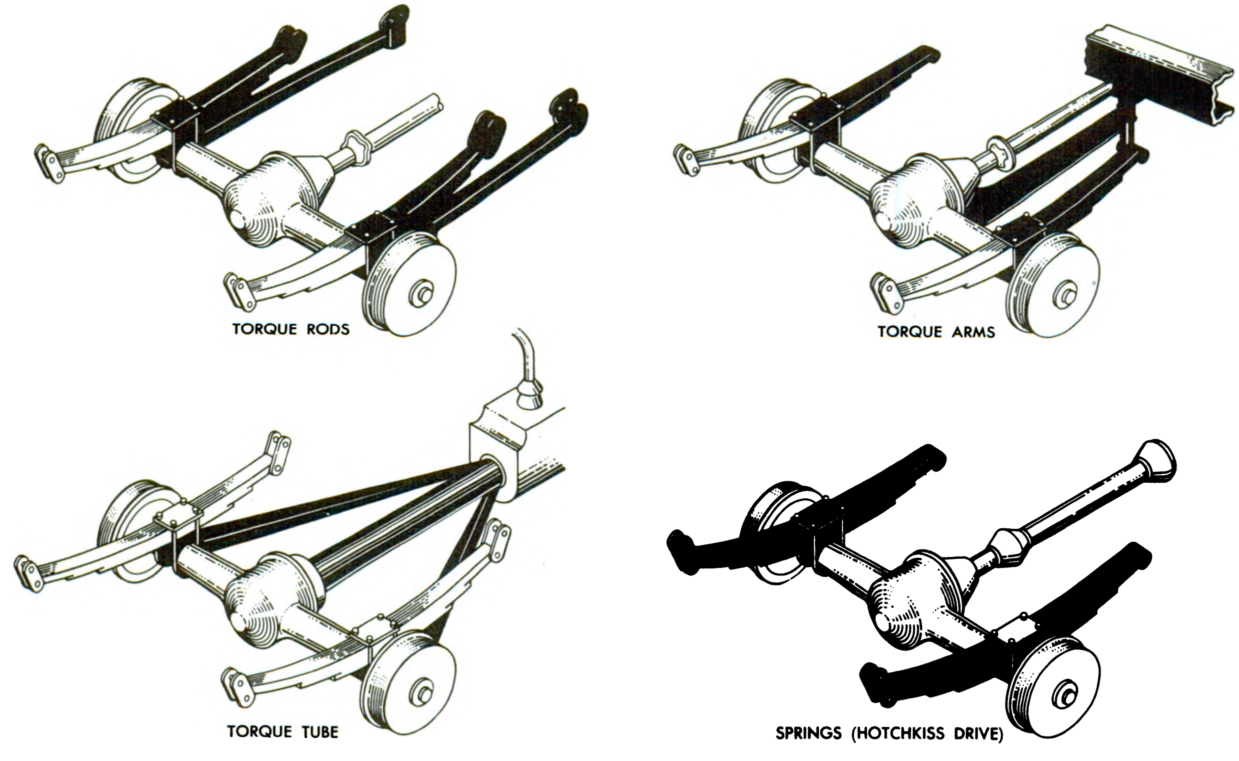

TRANSFER CASE TO PILLOW BLOCK PROPELLER SHAFT
FRONT REAR AXLE
DIFFERENTIAL AND CARRIER
REAR REAR AXLE
FRONT AXLE
POWER-TAKE-OFF
INTERMEDIATE PROPELLER SHAFT
TRANSFER CASE
TRANSMISSION
FRONT AXLE PROPELLER SHAFT
DIFFERENTIAL AND CARRIER
REAR REAR AXLE PROPELLER SHAFT
DIFFERENTIAL AND CARRIER
FRONT REAR AXLE PROPELLER SHAFT
RA PD 53427

Figure 285. Power transmission system in 6 x 6 wheeled vehicle.



TORQUE RODS

TORQUE ARMS

TORQUE TUBE

SPRINGS (HOTCHKISS DRIVE)

RA PD 183926

Figure 286. Types of drive and live axle suspensions.

methods, are used for accomplishing this result. They are radius rod drive, torque tube drive, torque arm drive, and Hotchkiss drive (fig. 286).

(1) In the radius rod drive, two radius rods (sometimes known as *torque rods*) are used to transmit the driving thrust to the frame and to maintain the alinement of the rear axle. The radius rods are connected both to the rear axle and to the frame by jointed connections which permit full vertical, and sometimes lateral, movement of the axle housing relative to the frame. Therefore, the torque reaction is resisted by the springs, as in the Hotchkiss drive. An open propeller shaft with two universal joints is usually employed with the radius rod drive. This type of drive is used only to a very limited extent.

(2) The torque tube drive is used on a number of passenger and light commercial vehicles. In this type drive the propeller shaft is housed in a steel tube. The rear end of the tube is rigidly bolted to the rear axle housing by a flange, and its front end is connected to the transmission or a frame cross member through a ball-and-socket joint. One universal joint, the center of which is placed at the center of the ball-and-socket joint of the torque tube, is used in the propeller shaft. A slip joint is used in the propeller shaft, since there is some lengthening and shortening of the shaft as the rear axle moves up and down. A center bearing for the propeller shaft is generally put in the torque tube. Two radius rods connect the ends of the axle housing with the forward end of the torque tube and maintain the axle housing alined at right angles to the torque tube. The springs are shackled at both ends. With this type drive, both the torque reaction and the driving thrusts are taken by the torque tube. Since the springs are relieved from both torque reaction and driving thrust, they can be made flexible, which it is thought imparts better rid-

ing qualities to the vehicle than other types of drive. When the torque tube drive is employed, the driving pressure is applied toward the forward end of the frame, either through the engine mountings or a frame cross member; whereas, in the torque rod and Hotchkiss drives, it is applied at the rear of the frame. Some designers prefer one and some the other. Both are satisfactory.

(3) The torque arm drive is seldom used. It consists of a solid or tubular arm, rigidly connected to the axle housing at its rear end and connected to a frame cross member through a ball-and-socket joint or a bracket similar to a spring bracket at its front end. An open propeller shaft is used. The torque arm drive is very similar to the torque tube drive, the principal difference being that it employs an open propeller shaft parallel to a torque arm instead of a housed propeller shaft within a torque tube.

(4) The Hotchkiss drive is used for a large proportion of the passenger cars and most of the heavier trucks. In this type drive, an open propeller shaft with two universal joints and a slip joint is used. The torque reaction, driving thrust, and alinement of the axle housings are all taken care of by the springs. The springs are pivoted on the brackets riveted to the vehicle frame at their forward ends and shackled to the frame at their rear ends. The rear spring brackets are the point of application of the driving thrust to the frame. Because the springs must take the torque reaction, stiffer springs are required than for the torque tube drive. Because they must take the driving thrust, they must be fairly straight or flat. Some designers think these considerations make for inferior riding qualities, but Hotchkiss drives are used very extensively with complete satisfaction. An advantage of the Hotchkiss drive is that the flexible connection between axle and frame throws less strain on the driving mechanism than do other types. When sudden loads are applied, as in letting the clutch in suddenly or quickly applying the brakes, the axle housing can rock slightly, which cushions the shock on the parts and prevents extremely high pressures between the gear teeth of the final-drive mechanism.

190. Basic Power Trains — Tracklaying Vehicles

a. General. The power trains in tracklaying vehicles perform the same function as in wheeled vehicles. They are designed for operating under more rugged conditions, however, and therefore are of more sturdy construction and, in general, provide for greater gear reduction.

b. Differences Due To Steering Arrangements. Full-track vehicles are steered by varying the speed of one track in relation to the other, and this leads to the most important differences between wheeled and tracklaying vehicles.

(1) In some full-track vehicles, clutches are used in the final drive to each sprocket. By engaging and disengaging the clutches, the relative speed of the tracks can be controlled by the driver. This system is satisfactory for slow-speed vehicles.

(2) In modern high-speed vehicles, steering is accomplished by means of a controlled differential. This differential employs a system of planetary gear trains, allowing power to be applied to both tracks at all times and still permitting the operator to regulate their relative speeds. This is illustrated in figures 287 and 288. The cross-drive transmission is one form of controlled differential used on late-type tanks; it utilizes a system of planetary gear trains as in other controlled differentials, but it also contains a torque converter (ch. 14).

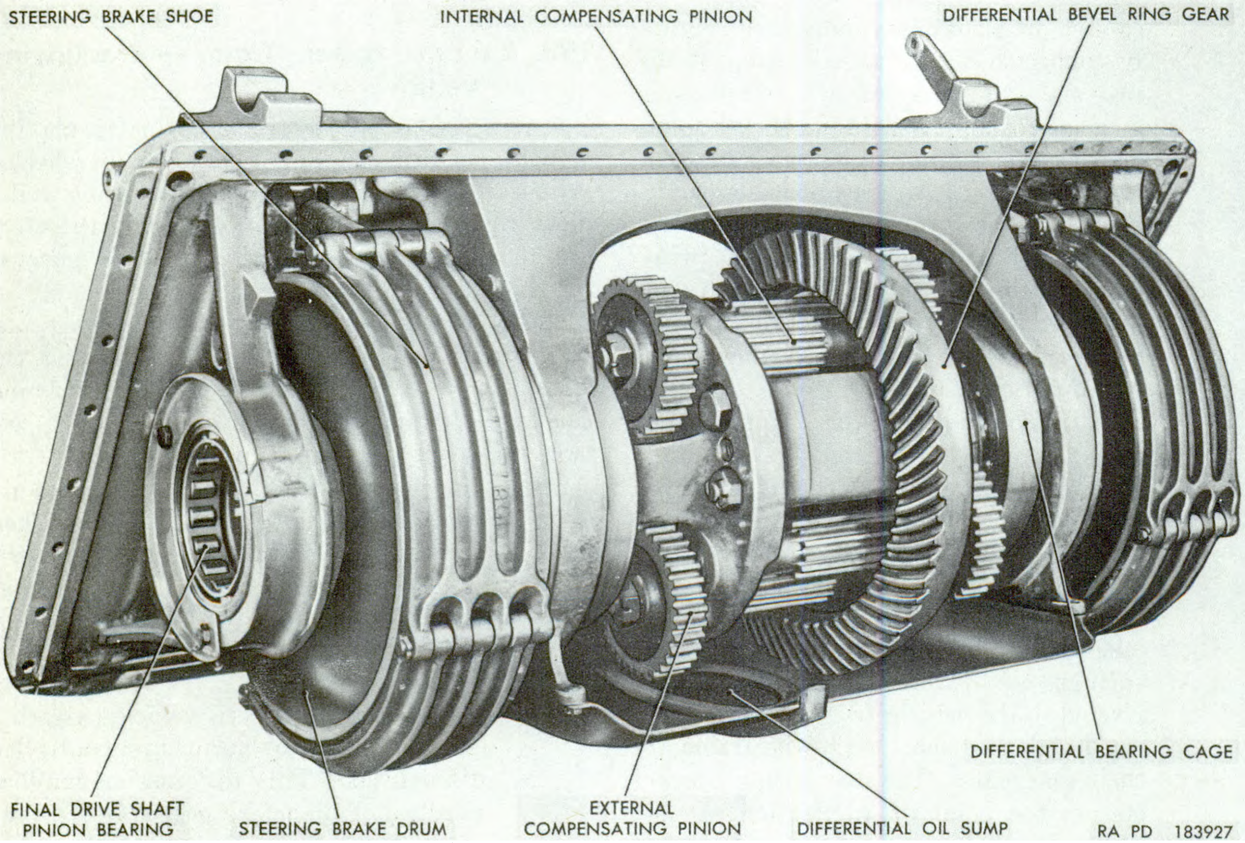

STEERING BRAKE SHOE
INTERNAL COMPENSATING PINION
DIFFERENTIAL BEVEL RING GEAR
DIFFERENTIAL BEARING CAGE
FINAL DRIVE SHAFT PINION BEARING
STEERING BRAKE DRUM
EXTERNAL COMPENSATING PINION
DIFFERENTIAL OIL SUMP
RA PD 183927

Figure 287. Controlled differential with planetary gear trains.

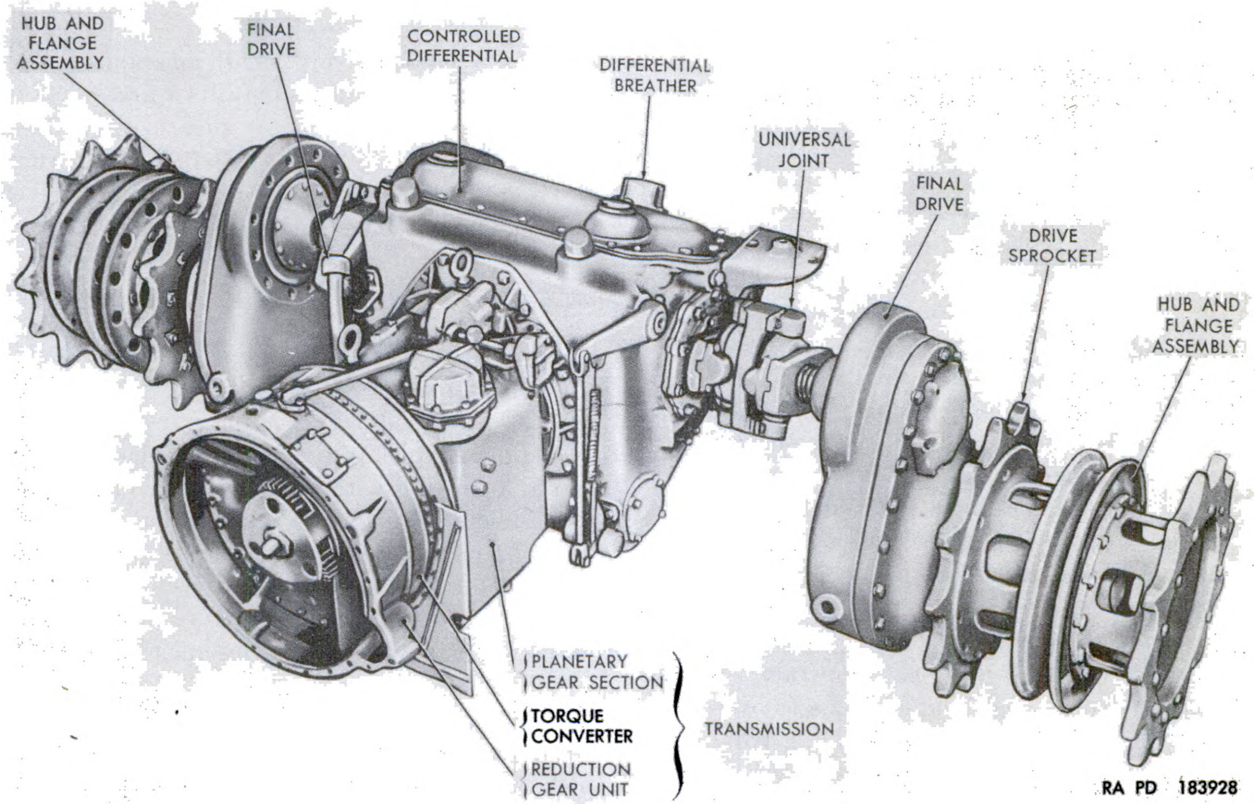

HUB AND FLANGE ASSEMBLY
FINAL DRIVE
CONTROLLED DIFFERENTIAL
DIFFERENTIAL BREATHER
UNIVERSAL JOINT
FINAL DRIVE
DRIVE SPROCKET
HUB AND FLANGE ASSEMBLY
PLANETARY GEAR SECTION
TORQUE CONVERTER
REDUCTION GEAR UNIT
TRANSMISSION
RA PD 183928

Figure 288. Controlled differential, final drives, and associated parts.

CHAPTER 14

CLUTCHES, FLUID COUPLINGS, AND TORQUE CONVERTERS

Section I. CLUTCHES

191. Clutch Principles

a. Automotive clutches depend on friction for their operation, whether it be solid friction as in the conventional clutch, or fluid friction and inertia as utilized in the fluid coupling and torque converter. The fluid coupling serves the same purpose as the conventional clutch, but the difference in the principle of operation makes it necessary to discuss the two mechanisms separately. Therefore, the first part of this chapter will be concerned with conventional clutches; fluid couplings and torque converters will be discussed in paragraphs 195 through 198.

b. A clutch in an automotive vehicle provides a means of connecting and disconnecting the engine from the power transmission system. Since the internal combustion engine does not develop a high starting torque, it must be disconnected from the power train and allowed to operate without load until it develops enough torque to overcome the inertia of the vehicle when starting from rest. The application of the engine power to the load must be gradual, to provide smooth engagement and to lessen the shock on the driving parts. After engagement, the clutch must transmit all the engine power to the transmission without slipping. Further, it is desirable to disconnect the engine from the power train during the time the gears in the transmission are being shifted from one gear ratio to another.

c. The transmission of power through the clutch is accomplished by bringing one or more rotating drive members secured to the crankshift into gradual contact with one or more driven members secured to the unit being driven. These members are either stationary or rotating at different speeds. Contact is established and maintained by strong spring pressure controlled by the driver through the clutch pedal and suitable linkage. As spring pressure increases, the friction increases; therefore, when the pressure is light, the comparatively small amount of friction between the members permits a great deal of slippage. As the spring pressure increases, less slippage occurs until, when the full spring pressure is applied, the speed of the driving and driven members is the same. All slipping has stopped and there is, in effect, a direct connection between the driving and driven parts.

192. Clutch Elements

The principal parts of a clutch are: the driving members, attached to the engine and turning with it; the driven members attached to the transmission and turning with it; the operating members which include the spring or springs and the linkage required to apply and release the pressure which holds the driving and driven members in contact with each other. Figure 289 shows a clutch cut away so operating members can be seen.

a. Driving Members. The driving members of a clutch usually consist of two cast-iron plates or flat surfaces machined and ground to a smooth finish. Cast iron is desirable because it contains enough graphite to provide some lubrication when the driving member is slipping during engagement. One of these surfaces is usually the rear face of the engine flywheel, and the other is a comparatively heavy flat ring with one side machined and surfaced. This part is known as the *pressure plate.* It is fitted into a steel cover, which also contains some of the operating members, and is bolted to the flywheel.

b. Driven Members.

(1) The driven member is a disk with a splined hub which is free to slide lengthwise along the splines of the clutch shaft. but which drives the shaft through these same splines. (The driven member is sometimes referred to as the *clutch plate.* but in this text the word *disk* will be used

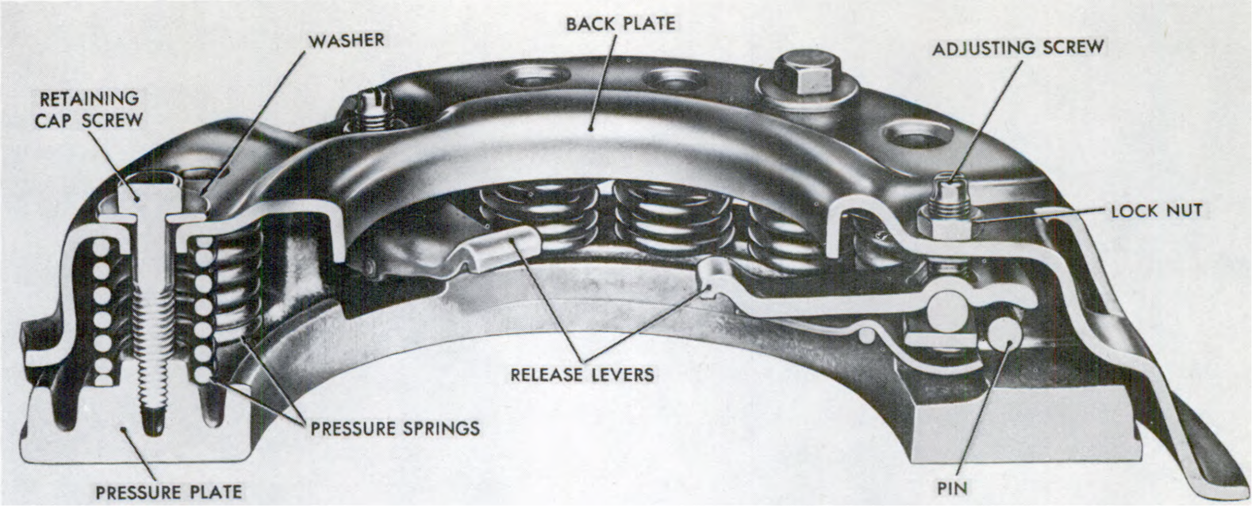

BACK PLATE
WASHER
ADJUSTING SCREW
RETAINING CAP SCREW
LOCK NUT
RELEASE LEVERS
PRESSURE SPRINGS
PRESSURE PLATE
PIN
RA PD 324417

Figure 289. Helical pressure spring disk-type clutch.

to denote the driven member and thus differentiate between this part and the clutch pressure plate.) The clutch disk is usually made of spring steel in the shape of a single flat disk of a number of flat segments. Suitable frictional facings are attached to each side of the disk by means of copper rivets. These facings must be heat resistant since friction produces heat. The most commonly used facings are made of cotton and asbestos fibers woven or molded together and impregnated with resins or similar binding agents. Very often, copper wires are woven or pressed into the material to give it additional strength.

(2) In order to make clutch engagement as smooth as possible and eliminate chatter, several methods have been used to give a little flexibility to the driven disk. One type of disk is "dished," so that the inner and outer edges of the friction facing make contact with the driving members first, and the rest of the facing makes contact gradually as the spring pressure increases and the disk is flattened out. In another type, the steel segments attached to the splined hub are slightly twisted, which also causes the facings to make gradual contact as the disk flattens out.

(3) The driven member of the clutch (fig. 290) is usually provided with a flexible center to absorb the torsional vibration of the crankshaft which would be transmitted to the power train unless it were eliminated. The flexible center usually takes the form of steel compression springs placed between the hub and the steel disk. The springs permit the disk

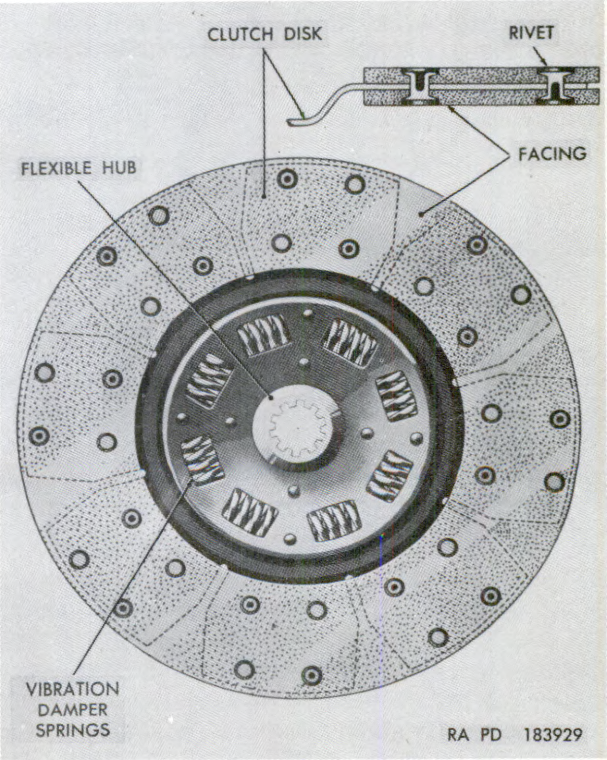

CLUTCH DISK
RIVET
FACING
FLEXIBLE HUB
VIBRATION DAMPER SPRINGS
RA PD 183929

Figure 290. Clutch driven plate with flexible center.

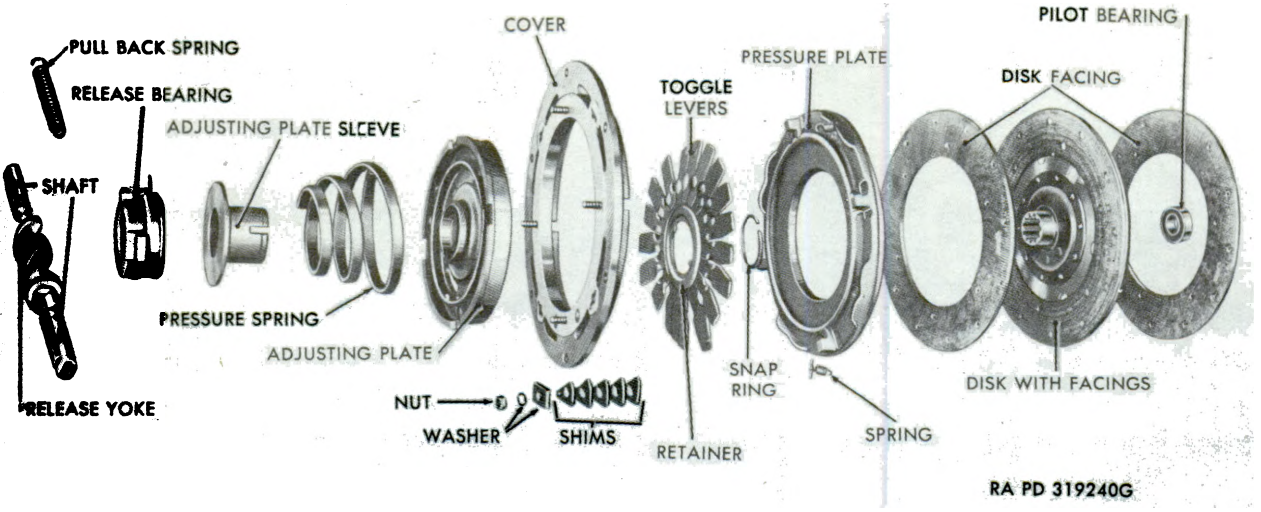

PULL BACK SPRING
RELEASE BEARING
ADJUSTING PLATE SLEEVE
SHAFT
PRESSURE SPRING
ADJUSTING PLATE
RELEASE YOKE
COVER
NUT
WASHER
SHIMS
TOGGLE LEVERS
RETAINER
PRESSURE PLATE
SNAP RING
SPRING
DISK FACING
DISK WITH FACINGS
PILOT BEARING
RA PD 319240G

Figure 291. Single, large coil pressure spring clutch—exploded view.

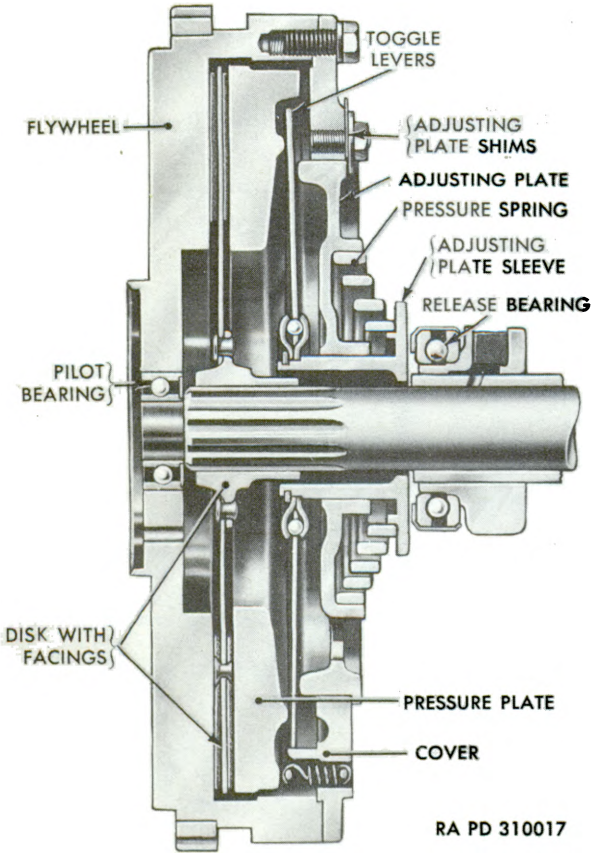

TOGGLE LEVERS
FLYWHEEL
ADJUSTING PLATE SHIMS
ADJUSTING PLATE
PRESSURE SPRING
ADJUSTING PLATE SLEEVE
RELEASE BEARING
PILOT BEARING
DISK WITH FACINGS
PRESSURE PLATE
COVER
RA PD 310017

Figure 292. Single, large coil pressure spring clutch—cross sectional view.

to rotate slightly with relation to its hub until, under extreme conditions, the springs are fully compressed and relative motion stops. Then the disk can rotate slightly backward as the springs decompress. This slight backward and forward rotation permitted by the springs allows the clutch shaft to rotate at a more uniform rate than the crankshaft, thereby eliminating some of the torsional vibration from the crankshaft and preventing the vibration from being carried back through the transmission.

c. Operating Members. The driving and driven members are held in contact by spring pressure. This pressure may be exerted by a single, large coil spring as shown in figures 291 and 292; a number of small helical springs located circumferentially around the outer portion of the pressure plate as shown in figure 289; or a one-piece conical or diaphragm spring as shown in figures 293 and 294. In the helical-spring clutches a system of levers pivoted on the cover forces the pressure plate away from the driven disk and against the pressure of the springs whenever the clutch release bearing moves forward against the inner ends of the levers. In single-spring clutches, the large coil spring holds the plates in contact. In diaphragm clutches, the dish-shaped diaphragm performs the same function. The clutch release (or throw-out) bearing is a ball-thrust bearing contained in the clutch release bearing housing, or collar, mounted on a sleeve attached to the front of the transmission case. The release bearing (P, figs. 294 and 295) is connected through linkage to the clutch, and is moved by the release yoke to engage the release levers and move the pressure plate to the rear, thus separating the

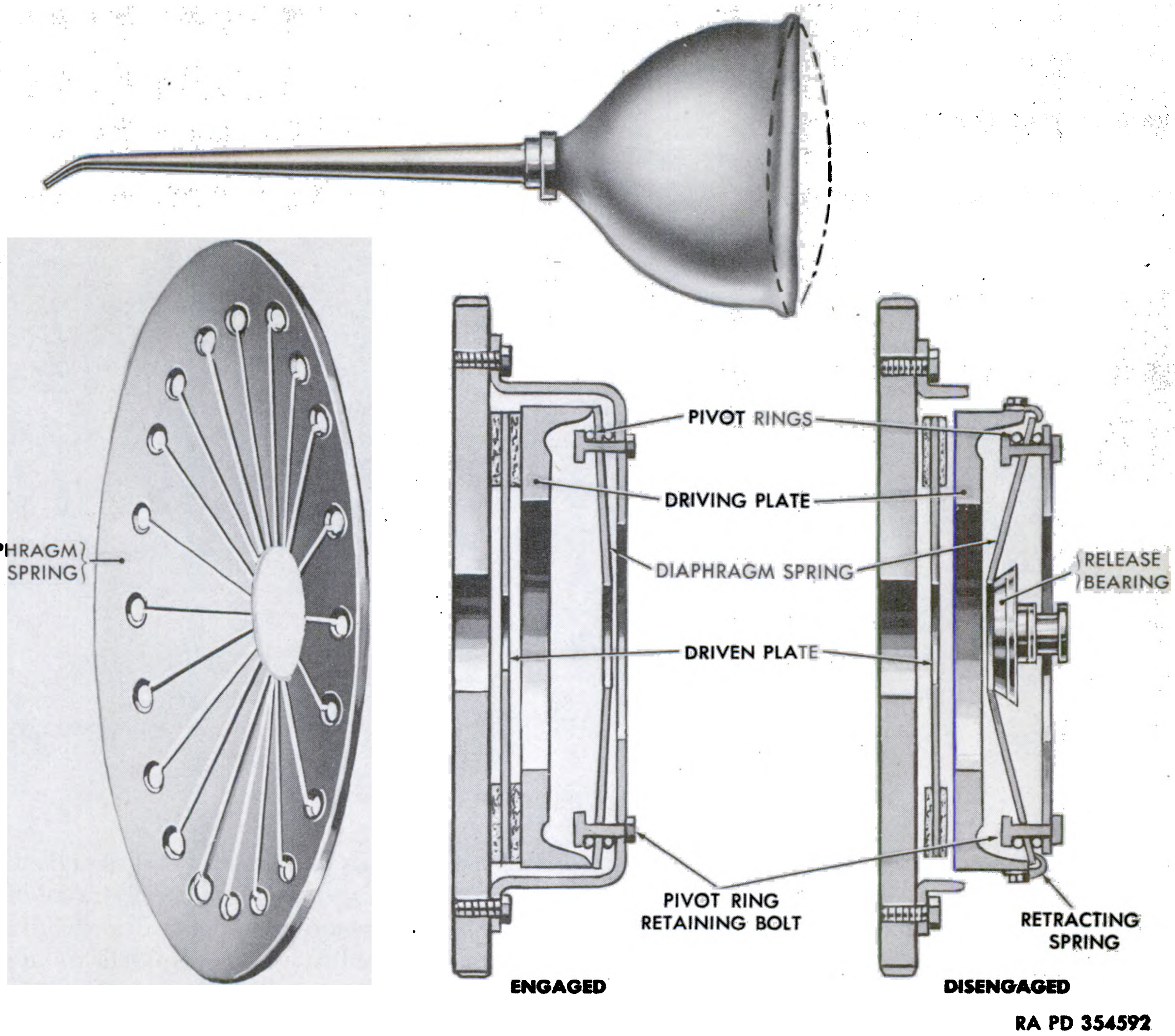


Figure 293. Diaphragm spring clutch operation.

clutch driving members from the driven member when the clutch pedal is depressed by the driver.

193. Clutch Operation

a. The operation of the clutch (fig. 295) is as follows: when the clutch is fully engaged, the driven disk is firmly clamped between the flywheel and the pressure plate by the pressure of the springs. When the driver disengages the clutch by depressing the pedal, the release yoke or fork is moved on its pivot, and pressure is applied to the release bearing sleeve, or collar, containing the release bearing. The rotating race of the release bearing presses against the clutch release levers and moves them on their pivot pins. The outer ends of the release levers, being fastened to the cover, move the pressure plate to the rear, compressing the clutch springs and allowing the driving members to rotate independently of the driven member. The release yoke moves only on its pivot, which is fastened to the flywheel housing by means of a bracket or a transverse shaft. All parts of the clutch, except the release bearing and collar, rotate with the flywheel when the clutch is engaged. When the clutch is disengaged, the release bearing rotates with the flywheel, but the driven disk and the clutch shaft come to rest.

b. In some clutches, a diaphragm is used instead of coil springs. It is a conical piece of spring steel punched as shown in figure 294 to give it greater flexibility. The diaphragm is positioned between the cover and the pressure plate so that the diaphragm spring is nearly flat when the clutch is in the engaged position. The action of

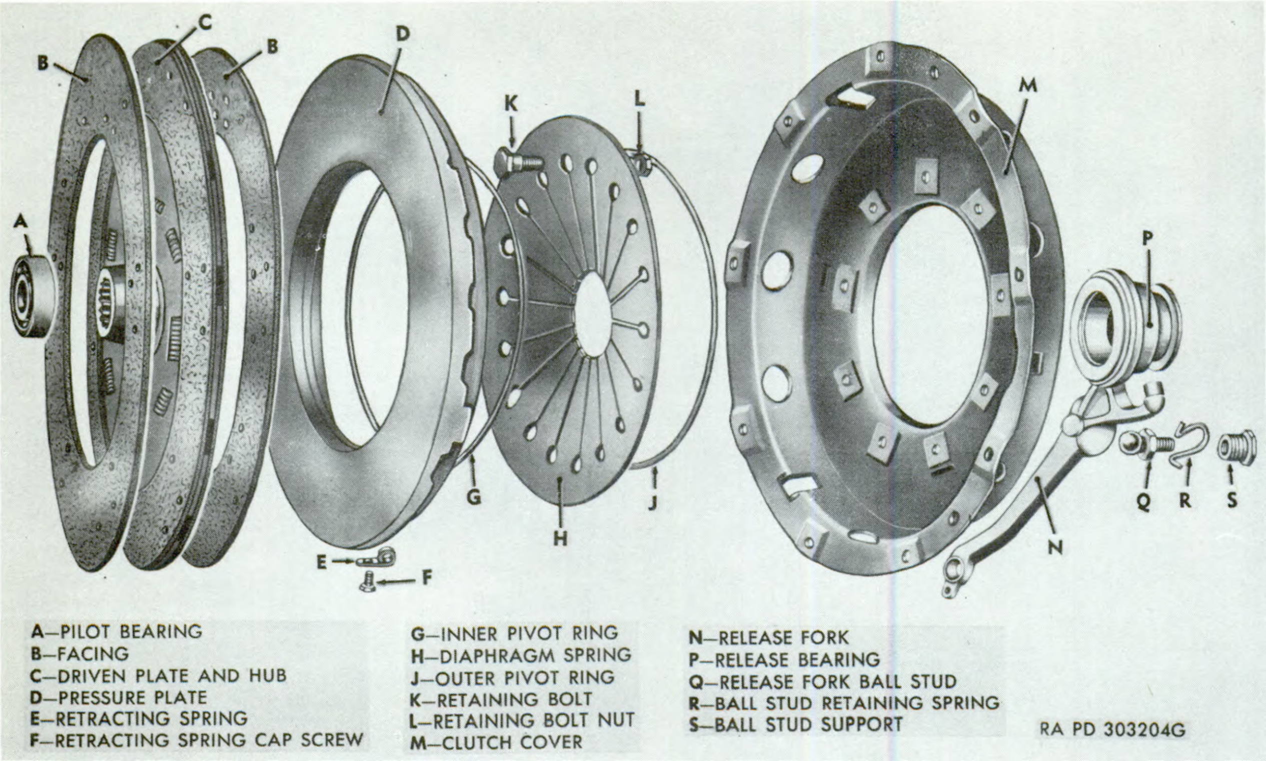

A
B
C
B
D
K
L
M
P
G
H
J
E
F
Q
R
S
N
A—PILOT BEARING
B—FACING
C—DRIVEN PLATE AND HUB
D—PRESSURE PLATE
E—RETRACTING SPRING
F—RETRACTING SPRING CAP SCREW
G—INNER PIVOT RING
H—DIAPHRAGM SPRING
J—OUTER PIVOT RING
K—RETAINING BOLT
L—RETAINING BOLT NUT
M—CLUTCH COVER
N—RELEASE FORK
P—RELEASE BEARING
Q—RELEASE FORK BALL STUD
R—BALL STUD RETAINING SPRING
S—BALL STUD SUPPORT
RA PD 303204G

Figure 294. Diaphragm spring clutch—Disassembled view.

this type of spring is similar to that of the bottom of an ordinary oil can (fig. 293). The pressure of the outer rim of the spring on the pressure plate increases until it reaches the flat position and decreases as this position is passed. The outer rim of the diaphragm is secured to the pressure plate and is pivoted on rings approximately 1 inch in from the outer edge so that the application of pressure at the inner section will cause the outer rim to move away from the flywheel and draw the pressure plate away from the clutch disk, releasing or disengaging the clutch. When the pressure is released from the inner section, the oil-can action of the diaphragm causes the inner section to move out, and the movement of the outer rim forces the pressure plate against the clutch disk, thus engaging the clutch.

194. Types of Clutches

a. Automotive clutches may be classified according to the number of plates or disks used. The single-plate clutch contains one driven disk operating between the flywheel and the pressure plate (fig. 295). The flywheel is not considered to be a plate, even though it acts as one of the driving surfaces. A double-plate clutch is substantially the same except that another driven disk and an intermediate driving plate (fig. 296) are added. A clutch having more than three driven disks (fig. 297) is referred to as a multiple-disk clutch. A further classification based on whether or not oil is supplied to the fraction surfaces provides a positive method of identifying the many types of clutches in use: if oil is supplied, the clutch is known as the *wet type;* if oil is not supplied, the clutch is the *dry type.* Difference in the action of the clutches is largely a difference in the time of operation, the time required to engage the clutch depending on the number of plates and the condition of the surfaces. A plate clutch will engage the load and start it in motion sooner than will a multiple-disk clutch. A dry clutch will be quicker to act than a wet clutch, in which the oil must be squeezed out from between the driven and driving members before engagement is accomplished. Plate clutches are generally used on light and medium weight vehicles, and the multiple-disk clutch on heavier vehicles in which the sudden action of the other type would impose a severe shock on the engine and power train when starting a heavy load.

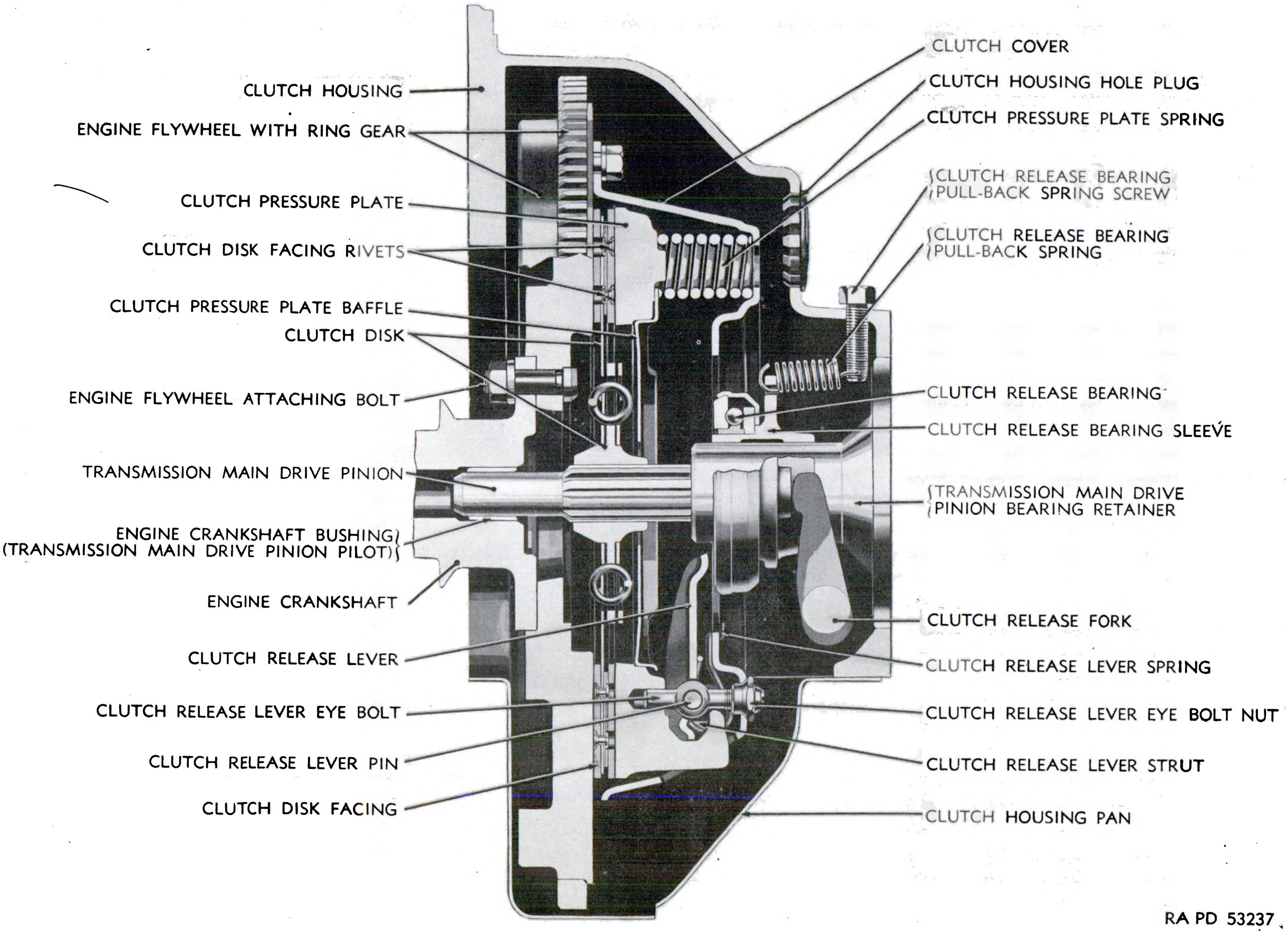

CLUTCH HOUSING
ENGINE FLYWHEEL WITH RING GEAR
CLUTCH PRESSURE PLATE
CLUTCH DISK FACING RIVETS
CLUTCH PRESSURE PLATE BAFFLE
CLUTCH DISK
ENGINE FLYWHEEL ATTACHING BOLT
TRANSMISSION MAIN DRIVE PINION
ENGINE CRANKSHAFT BUSHING (TRANSMISSION MAIN DRIVE PINION PILOT)
ENGINE CRANKSHAFT
CLUTCH RELEASE LEVER
CLUTCH RELEASE LEVER EYE BOLT
CLUTCH RELEASE LEVER PIN
CLUTCH DISK FACING
CLUTCH COVER
CLUTCH HOUSING HOLE PLUG
CLUTCH PRESSURE PLATE SPRING
CLUTCH RELEASE BEARING PULL-BACK SPRING SCREW
CLUTCH RELEASE BEARING PULL-BACK SPRING
CLUTCH RELEASE BEARING
CLUTCH RELEASE BEARING SLEEVE
TRANSMISSION MAIN DRIVE PINION BEARING RETAINER
CLUTCH RELEASE FORK
CLUTCH RELEASE LEVER SPRING
CLUTCH RELEASE LEVER EYE BOLT NUT
CLUTCH RELEASE LEVER STRUT
CLUTCH HOUSING PAN
RA PD 53237

Figure 295. Plate clutch—cross sectional view.

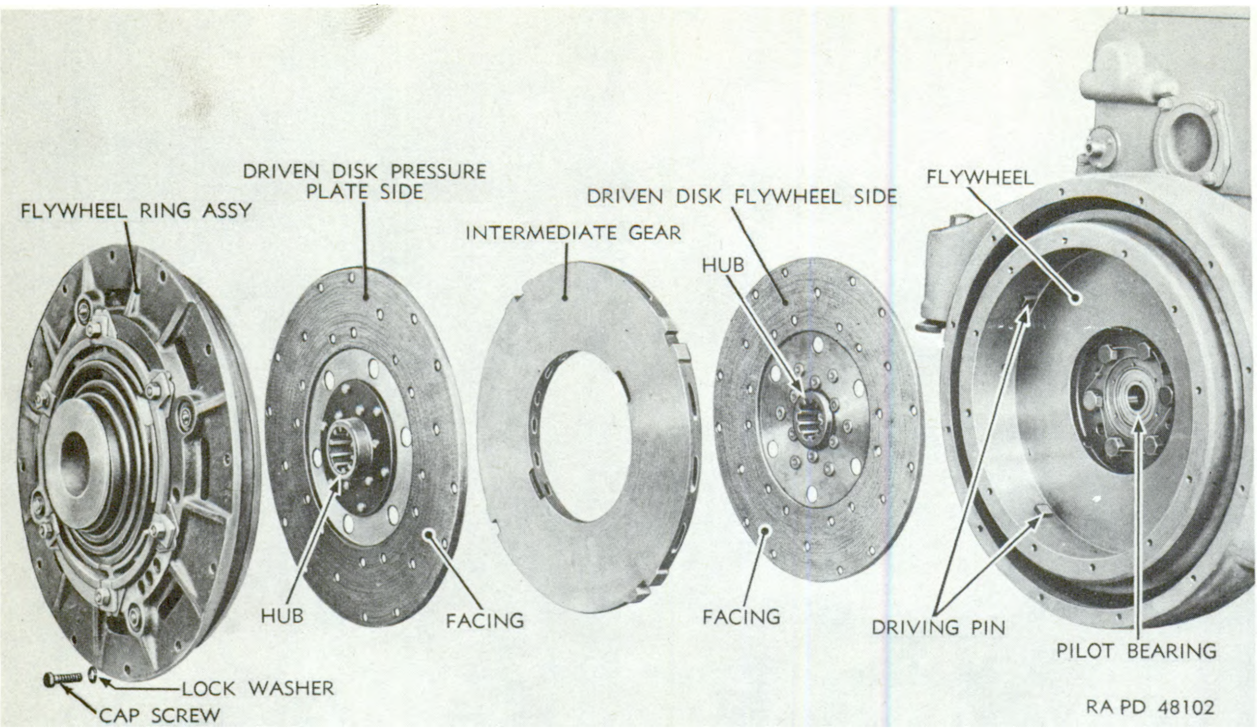


Figure 296. Disk clutch with two driven disks—disassembled view.

b. A typical multiple-disk clutch is shown in figure 297. A large number of disks are used, often as many as 11 driving and 10 driven disks for heavy vehicles. The driving disks have lugs similar to gear teeth around their outside edges. These mesh with internal splines in the clutch case, which is bolted to and rotates with the flywheel. The driven disks are carried on parallel pins which are solidly set in the clutch spider. This construction permits movement of all the disks and the pressure plate in order to provide clearance between them. When the clutch is engaged, the spring moves the pressure plate forward, holding all the disks firmly together. This causes the clutch spider to revolve and turn the clutch shaft to which it is keyed. In multiple-disk clutches, the facings are usually attached to the driving disks. This reduces the weight of the driven disks and, consequently, their tendency to continue spinning after the clutch is released. Because of the considerable number of disks involved, the pressure plate has to move farther to separate the disks completely than it does in clutches having fewer driving and driven members. There is, therefore, less mechanical advantage on the clutch pedal and a greater foot pressure is required to depress it.

c. In a wet-type clutch, the disks and the entire internal assembly run in an oil bath. The operation of this type of clutch is similar to that of the dry type, except that the friction surfaces are made of different materials and the gradual engagement between the driving and driven members is partially effected by pressing the oil from between the disks. As the oil is eliminated, the friction increases.

d. Many passenger car clutches are of the semi-centrifugal type shown in figure 298, in which the pressure between the plates is increased as the speed of the clutch increases. This is accomplished by means of centrifugal weights built into the outer ends of the release levers so that the outward pull of centrifugal force is transformed into pressure on the plate. This construction permits the use of relatively light clutch springs, thus facilitating the depression of the clutch pedal for gear shifting.

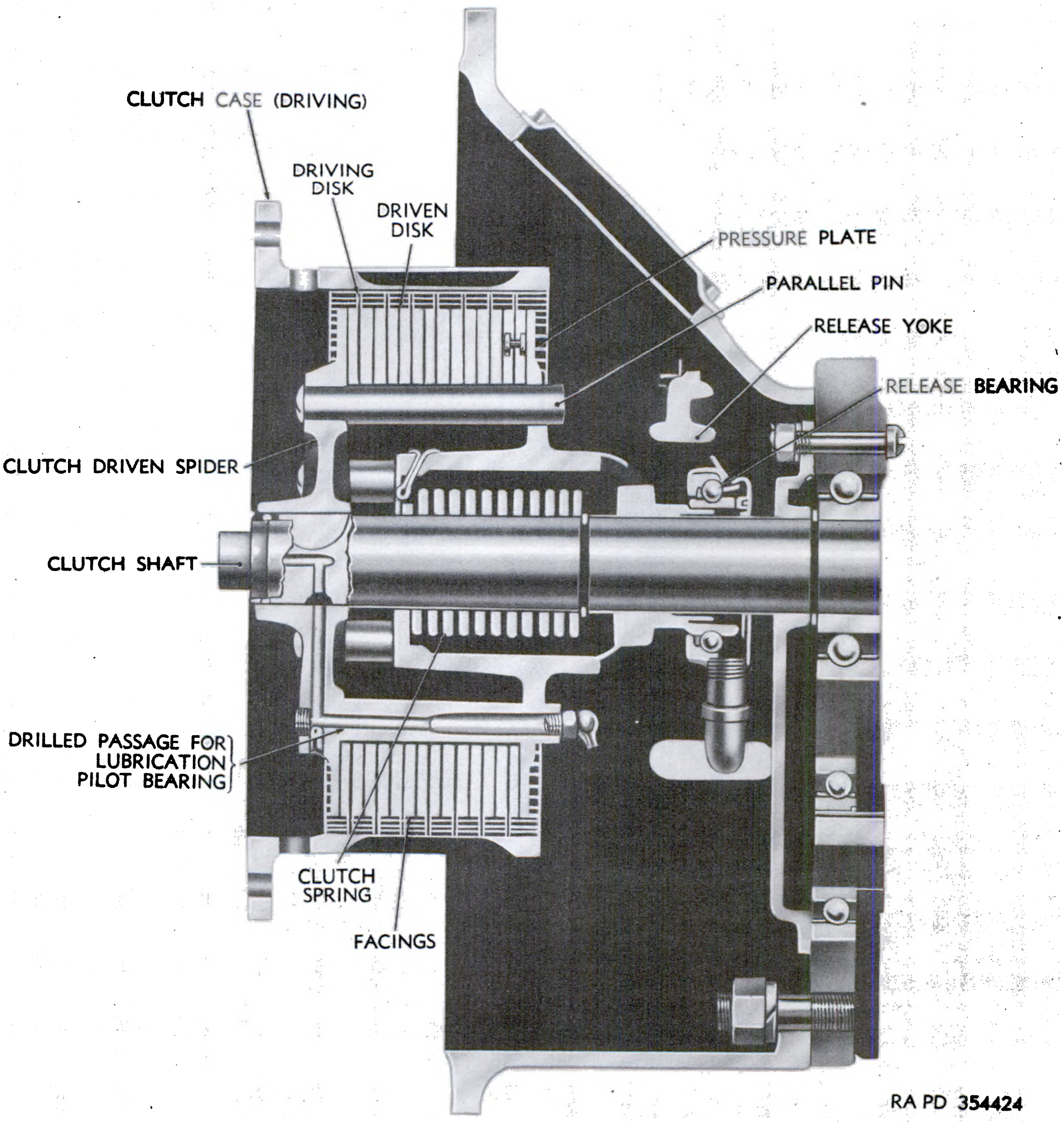

CLUTCH CASE (DRIVING)
DRIVING DISK
DRIVEN DISK
PRESSURE PLATE
PARALLEL PIN
RELEASE YOKE
RELEASE BEARING
CLUTCH DRIVEN SPIDER
CLUTCH SHAFT
DRILLED PASSAGE FOR LUBRICATION PILOT BEARING
CLUTCH SPRING
FACINGS
RA PD 354424

Figure 297. Multiple-disk clutch.

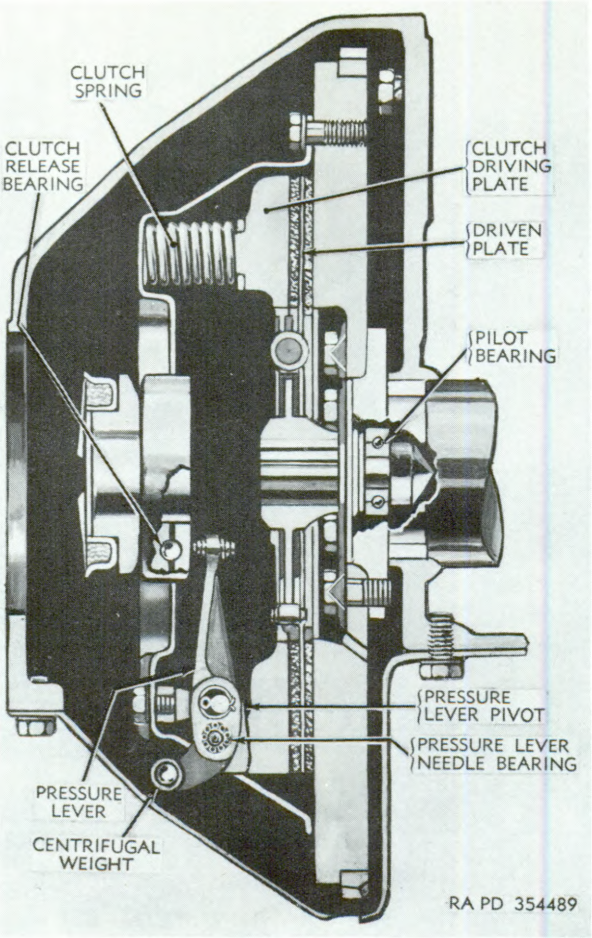


Figure 298. Semicentrifugal clutch—cross sectional view.

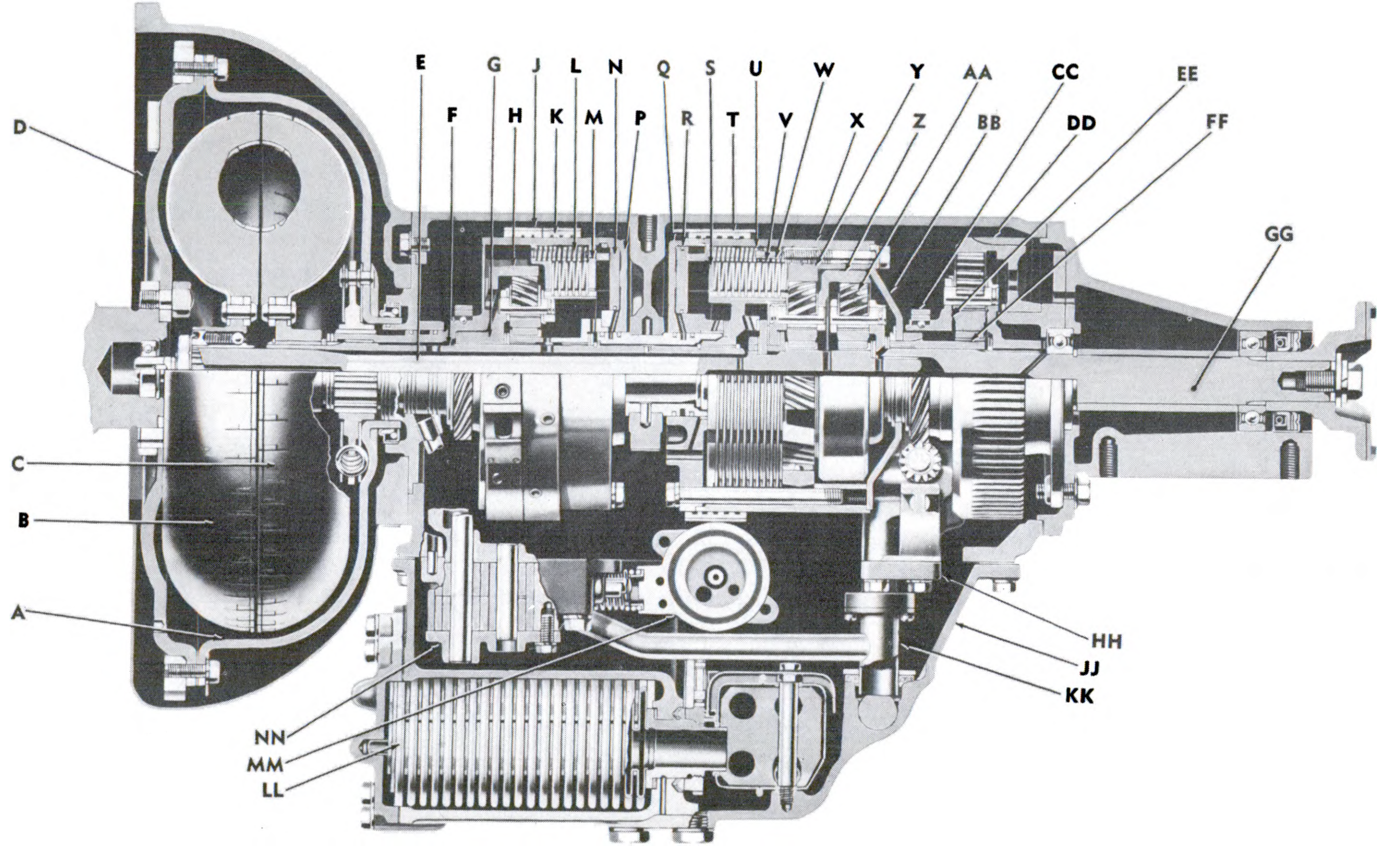
Section II. FLUID COUPLINGS

195. Principles

The fluid coupling (fig. 299) is used either with a conventional clutch and transmission or as a part of an automatic transmission, in which case it may replace the clutch. The principle of this type of drive is illustrated by the action of two electric fans, facing each other, one with the power connected and the other with the power disconnected. As the speed of the power-driven fan is increased, the flow of air transmits power to the motionless fan and it begins to rotate. The free-running fan gains speed until it is rotating almost as rapidly as the power-driven fan. The same action takes place in the fluid coupling except that oil instead of air transmits the power.

196. Operation

a. The fluid coupling consists of an impeller, or driving torus, driven by the engine and a turbine, or driven torus, mounted on the driven shaft. These parts are shown in figures 299 and 300 and depicted schematically in figure 301. There is no metallic connection between the two torus members. The assembly is enclosed by the flywheel and cover as shown in figure 299. The assembly is kept filled with oil under control of a relief valve, by means of high capacity pumps. When the crankshaft and impeller rotate, the oil is thrown by centrifugal force from the center to the outside edge of the impeller between the vanes. This increases the velocity of the oil and increases its energy. The oil then enters the turbine vanes at the outside and flows toward the center, imparting a rotating motion to the turbine. Both members of the drive are of similar construction so that when the vehicle is coasting in gear the wheels drive the engine. In this case, the oil circulates in a reverse direction. The engine can thus brake



A—FLYWHEEL COVER
B—DRIVEN TORUS
C—DRIVING TORUS
D—FLYWHEEL WITH RING GEAR
E—MAIN SHAFT
F—INTERMEDIATE SHAFT
G—FRONT UNIT PLANET CARRIER
H—FRONT UNIT DRIVE GEAR
J—FRONT UNIT BRAKE BAND
K—FRONT UNIT BRAKE DRUM
L—FRONT UNIT CLUTCH RELEASE SPRING
M—FRONT UNIT CLUTCH PRESSURE PLATE
N—FRONT UNIT CLUTCH DRUM PISTON
P—FRONT UNIT CLUTCH DRUM
Q—REAR UNIT CLUTCH DRUM
R—REAR UNIT CLUTCH DRUM PISTON
S—REAR UNIT CLUTCH PRESSURE PLATE
T—REAR UNIT BRAKE BAND
U—REAR UNIT CLUTCH RELEASE SPRING
V—REAR UNIT CLUTCH DRIVE PLATE
W—REAR UNIT CLUTCH DRIVEN PLATE
X—REAR UNIT BRAKE DRUM
Y—REAR UNIT INTERNAL GEAR
Z—REAR UNIT PLANET CARRIER
AA—DRIVEN SHAFT PLANET PINION
BB—REVERSE UNIT DRIVE FLANGE
CC—REAR OIL PUMP AND GOVERNOR DRIVE GEAR
DD—REVERSE UNIT INTERNAL GEAR
EE—REVERSE UNIT PLANET CARRIER
FF—REVERSE UNIT CENTER GEAR
GG—DRIVEN SHAFT
HH—REAR OIL PUMP AND GOVERNOR
JJ—OIL PAN
KK—REAR OIL PUMP INLET PIPE
LL—OIL COOLER
MM—REAR SERVO
NN—FRONT SERVO AND OIL PUMP

RA PD 183930

Figure 299. Fluid coupling and hydramatic transmission (including reverse speed)—cross sectional view.

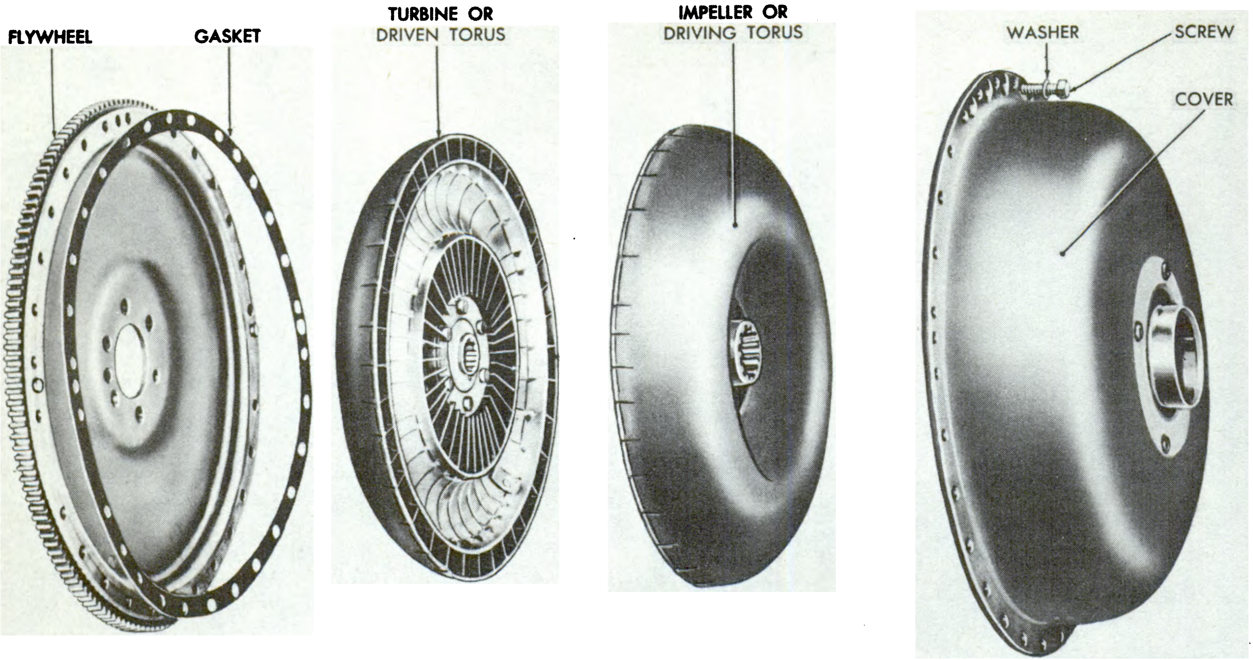

FLYWHEEL
GASKET
TURBINE OR DRIVEN TORUS
IMPELLER OR DRIVING TORUS
WASHER
SCREW
COVER
RA PD 183931

Figure 300. Fluid coupling—disassembled view.

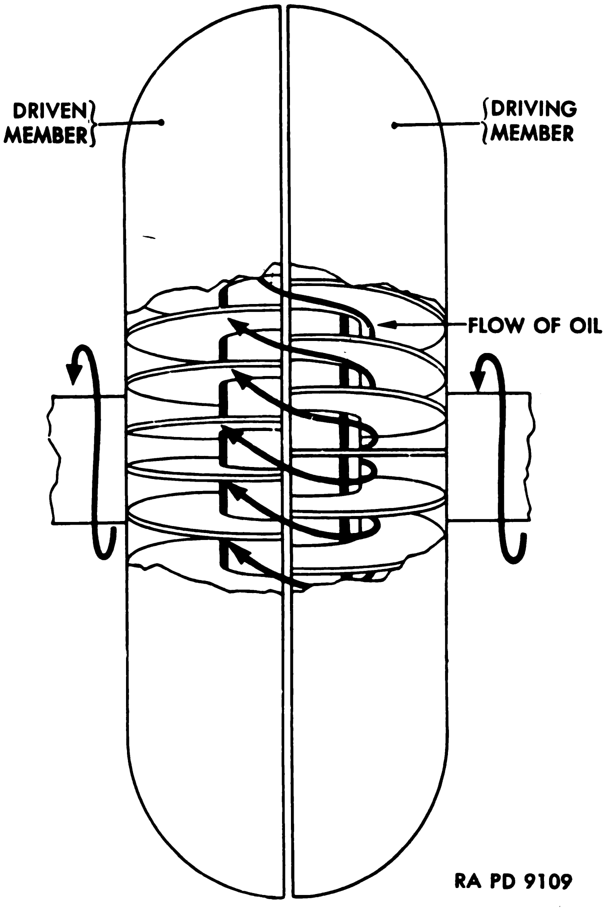

DRIVEN MEMBER
DRIVING MEMBER
FLOW OF OIL
RA PD 9109

Figure 301. Fluid coupling—schematic view.

the vehicle, as with a vehicle equipped with a conventional clutch.

b. When the engine is idling, the energy imparted to the oil is insufficient to rotate the turbine. As the amount of slip is determined by the torque required by the driven member, the slip is 100 percent with the vehicle stationary, but drops quickly as the vehicle gathers speed. In some arrangements, it is less than 1 percent during normal operation above 30 mph. The main advantage of the fluid coupling is that it eliminates torsional vibration and provides a smooth, jerkless acceleration because of the cushioning of the fluid medium between the two members.

Section III. TORQUE CONVERTERS

197. Principles

In some respects, the torque converter is like the fluid coupling described in paragraphs 195 and 196. It has driving and driven members with vanes. Oil is passed from the driving to the driven member when the coupling is in operation, thereby transmitting driving force to the driven member. However, in the torque converter, the vanes are curved and additional rotatable members provide the means of increasing torque through the unit. These additional members can reverse the direction of the moving oil before it re-enters the driving member; this nullifies any negative effect produced by vane curvature, as explained in paragraph 198. Thus, the torque converter acts not only as a fluid coupling, it also provides a speed-producing, torque-multiplying connection between the driving and the driven shafts. It can actually take the place of the conventional transmission since, with it, there is no need for gearshifting; the vehicle can be accelerated from a standing stop to high speed with the torque converter providing, in effect, the varying gear ratios. In actual practice, the torque converter is used with a gear system (including planetary gears) to provide a high range (for normal operation), a low range (for steep hills, pulling out of mud, etc.), reverse, and neutral. There may also be a parking position at which the gear system is locked.

198. Operation

a. All torque converters have a driven member (called the turbine) and a driving member (called the pump). In addition, they have one or more other rotatable members (or elements) placed between the pump and the turbine which have the purpose of changing the direction of oil flow under high-torque-multiplication operation. Figures 302 and 303 show torque converters in sectional and cutaway views.

b. The primary action of the torque converter results from the action of the pump in passing oil at an angle into the blades of the turbine (fig. 302). The oil pushes against the faces of the turbine vanes, thereby tending to cause the turbine to rotate in the same direction as the pump. If the pump is rotating much more rapidly than the turbine, the oil enters the turbine and pushes against the turbine vanes with great force. As the oil passes around through the turbine (fig. 303), it imparts force against the turbine vanes, all along the vanes. But it does not give up all of its force of motion to the turbine vanes. It still has considerable energy, even though passing through the turbine has reversed its direction

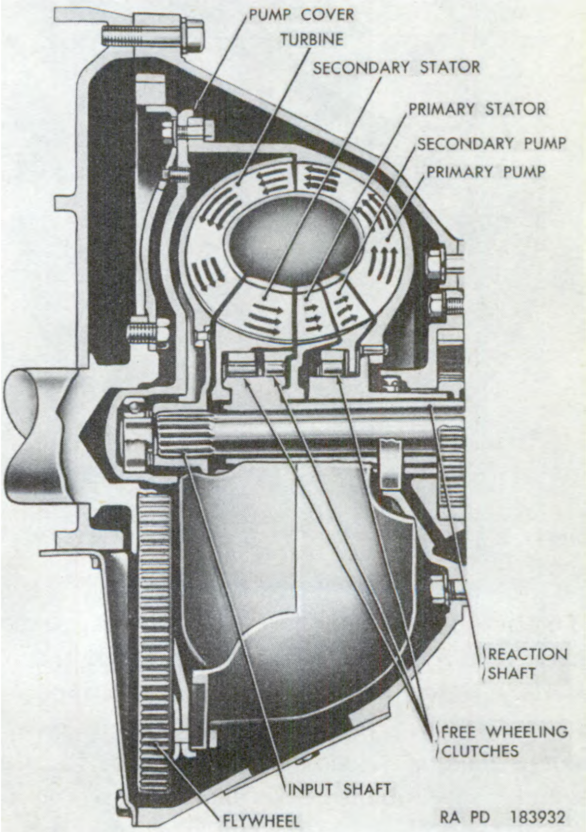


Figure 302. Torque converter (arrows show direction of oil flow)—partial cutaway view.

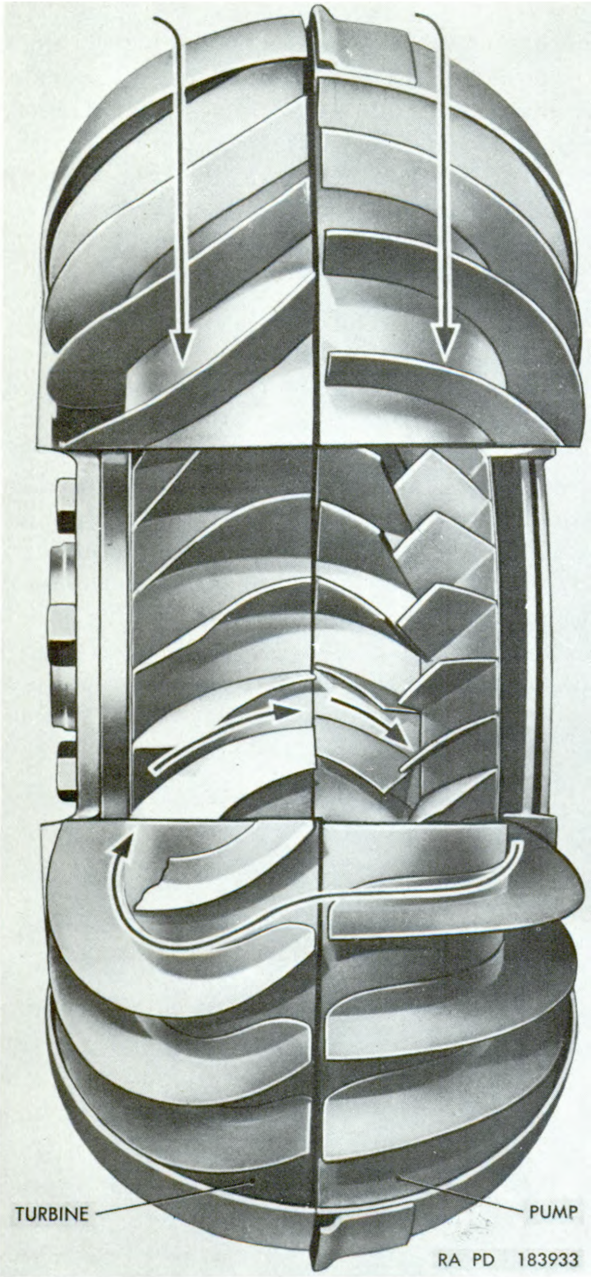


Figure 303. Torque converter cut away so curvature of vanes and direction of oil flow can be seen.

of motion as shown in figure 303. If this reversed direction of motion were not changed, the oil would re-enter the pump in a direction opposing pump rotation. It would act as a brake on the pump, tending to slow it down. Considerable engine power would be consumed in overcoming this action. However, the additional members in the torque converter again change the direction of the oil before it re-enters the pump, thereby avoiding loss of power. As can be seen in figure 304, the curved blades of the added members (secondary stator and primary stator) reverse the direction of the oil into a forward, or helping, direction before it re-enters the pump. Then, the oil is once more passed into the turbine from the pump, adding more "push" to the turbine vanes. During this action, the stators are stationary and act simply as oil-direction reversers.

c. It is this continuous passing of the oil from the pump into the turbine, back to the pump where it picks up more energy of motion, and then back into the turbine again, that produces the torque multiplication. Each time the oil passes from the pump to the turbine, it imparts a push to the turbine. The oil still has energy of motion after it leaves the turbine and is reversed in direction by the stators and secondary pump. When it comes around to the turbine again, it imparts more of this push to the turbine. Repeated applications of this push increases the total push so that, when the turbine is rotating at very slow speed with the pump rotating at high speed, the torque at the output shaft (attached to turbine) may be several times the torque at the input shaft (attached to the engine).

d. In actual operation, the secondary stator and primary stator are stationary when there is a great difference between pump and turbine speed. At the same time, the secondary pump is overrunning, or running faster than, the primary pump; the secondary pump does not enter into the converter action at all at this time. The secondary pump is mounted on a freewheeling or overrunning clutch very similar to the overrunning clutch used in automotive starters (par. 142*c*). The freewheeling clutch permits the secondary pump to run freely in one direction, but, when it attempts to slow down below shaft speed, it locks on the shaft because the rollers jam between the race and notches in the hub as shown in figure 304. However when the turbine is stopped or turning slowly and the pump is turning rapidly, the direction of oil flow is as shown by the arrows in figure 303. As it moves to the secondary pump, it strikes the back sides of the secondary pump vanes, pushing the secondary pump ahead so that it overruns. Under this condition, the secondary pump vanes are simply moving out of the way of the oil. The secondary pump enters the action

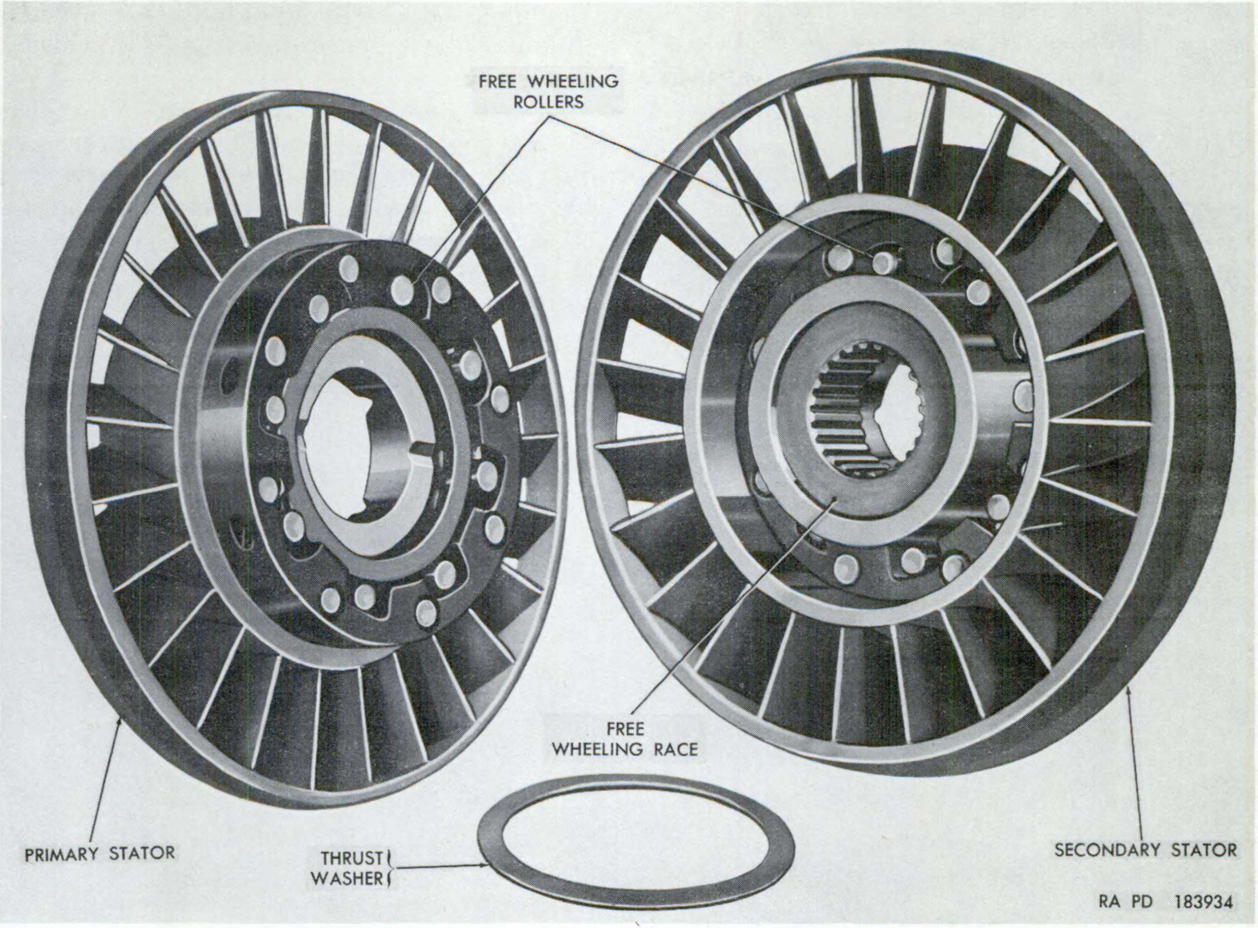


Figure 304. Primary and secondary stators showing freewheeling rollers.

only when the pump and turbine are turning at about the same speeds, as described in *e* and *f* below.

e. When the turbine speed increases due to the application of the torque, so that it turns at more nearly the same speed as the pump, the oil leaves the turbine vanes with less of the reverse direction of motion mentioned in *b* above. Consequently, it begins to strike the back sides of the secondary stator vanes so the secondary stator now begins to overrun on its overrunning clutch. It is no longer needed and therefore, in effect, it moves out of the way by overrunning or freewheeling.

f. When turbine speed increases to nearly pump speed, as for instance when cruising at steady speed along the highway, the oil leaves the turbine vanes with very little reverse direction of motion. The primary stator also begins to overrun, since the oil begins to strike the back sides of its vanes. At the same time, the oil begins to strike the front faces of the secondary pump vanes. The secondary pump stops overrunning and slows to primary pump speed. It now helps the primary pump and the two work together as a unit. Under these conditions, the torque converter functions like a fluid coupling.

g. While the foregoing description covers torque converters generally, some torque converters have more secondary members (aside from the pump and turbine) than others. The unit described is a 5-member torque converter, with a pump, turbine, primary stator, secondary stator, and secondary pump. Other torque converters have only four members, while still others have only three. In every case, the added units have the job of reversing the direction of oil movement as the oil leaves the turbine when there is considerable difference in turbine and pump speeds. In addition to these variations, some torque converters have a lockup clutch that locks out the converter above a certain speed. The clutch acts much like a conventional clutch, but it does not engage until a certain speed is reached. As it engages, it locks out the torque converter and thereby prevents any slippage between the driving and driven shafts.

h. Since torque converters vary considerably in design, the amount of torque multiplication they can achieve also varies. Practical limits seem to be 5:1. Many torque converters provide satisfactory operation with a much lower torque multiplication (some passenger car units provide less than 2.5:1).

i. Many torque converters have oil coolers. Since the oil is subjected to violent agitation and motion, it becomes hot. The oil cooler acts much like the radiator in liquid-cooling systems. As oil passes through the radiator, it gives up heat and emerges at a lower temperature.

CHAPTER 15

TRANSMISSIONS AND TRANSFER ASSEMBLIES

Section I. CONVENTIONAL TRANSMISSIONS

199. Function and Types

As explained in chapter 13, the purpose of the transmission is to provide the operator with a selection of gear ratios between engine and wheels so that the vehicle can operate at best efficiency under a variety of driving conditions and loads.

a. Basic Types. There are three basic types: the sliding gear, the planetary, and the friction-disk. The friction-disk is no longer used. The planetary, as such, is no longer used although it is incorporated in automatic transmissions using fluid couplings or torque converters, as well as in overdrives and in some dual-ratio rear axles. The sliding-gear type is now known as the conventional transmission. There are two types of sliding-gear transmissions. One is the progressive, in which the arrangement is such that it is necessary to pass one gear through another in definite order. Thus, in a three-speed progressive transmission, it is impossible to shift from "low" to "high" without going through "second." The use of this system is limited almost entirely to motorcycles. The other sliding-gear type is known as selective. In this system the operator can select any ratio without going through intermediate stages. Its construction and operation is explained in paragraph 201.

b. Special Types

(1) In modern passenger cars, the disadvantages of sliding-gear types are overcome by use of constant-mesh transmissions These eliminate the noise and clashing common to spur-gear trains. A more complete discussion will be found in paragraph 201*b*.

(2) Synchromesh transmissions are a type of constant-mesh. Their construction and operation are discussed in this chapter.

200. Construction and Operation

a. General. Conventional transmissions have certain fundamental components. These are the case, which houses the gears and shafts; the control cover, which houses the shifter mechanism; and the various shafts and gears. Three-speed selective transmissions have three shafts. They are, in the order of the flow of power, the input shaft, the countershaft, and the main shaft. The function of the three shafts, together with the gears which connect them, is discussed in detail.

b. Parts. The parts are shown in figure 305 in their correct relative positions but disassembled in the case. The names and functions of the parts follow:

(1) *Shafts.* The input shaft has an integral main drive gear and rotates with the clutch driven plate or disks; that is, the shaft rotates all the time the clutch is engaged and the engine is running. The main drive gear is in constant mesh with the countershaft drive gear. Since all the gears in the countershaft cluster are either made integral or keyed on, they also rotate at the time the clutch is engaged. The transmission main shaft is held in line with the input shaft by a pilot bearing at its front end, which allows it to rotate or come to rest independently of the input shaft.

(2) *Gears.* The transmission second-and-third and first-and-reverse speed main shaft gears have grooved hub extensions into which the shift forks are fitted that slide them back and forth on the main shaft splines. Thus, the second-and-third speed main shaft gear can be shifted rearward to mesh with the countershaft second-speed gear. The second-and-third speed main shaft gear also has internal teeth which mesh with the external teeth on the rear of the main drive gear when the gear is shifted forward into the direct-drive position. The first-and-reverse speed main shaft gear

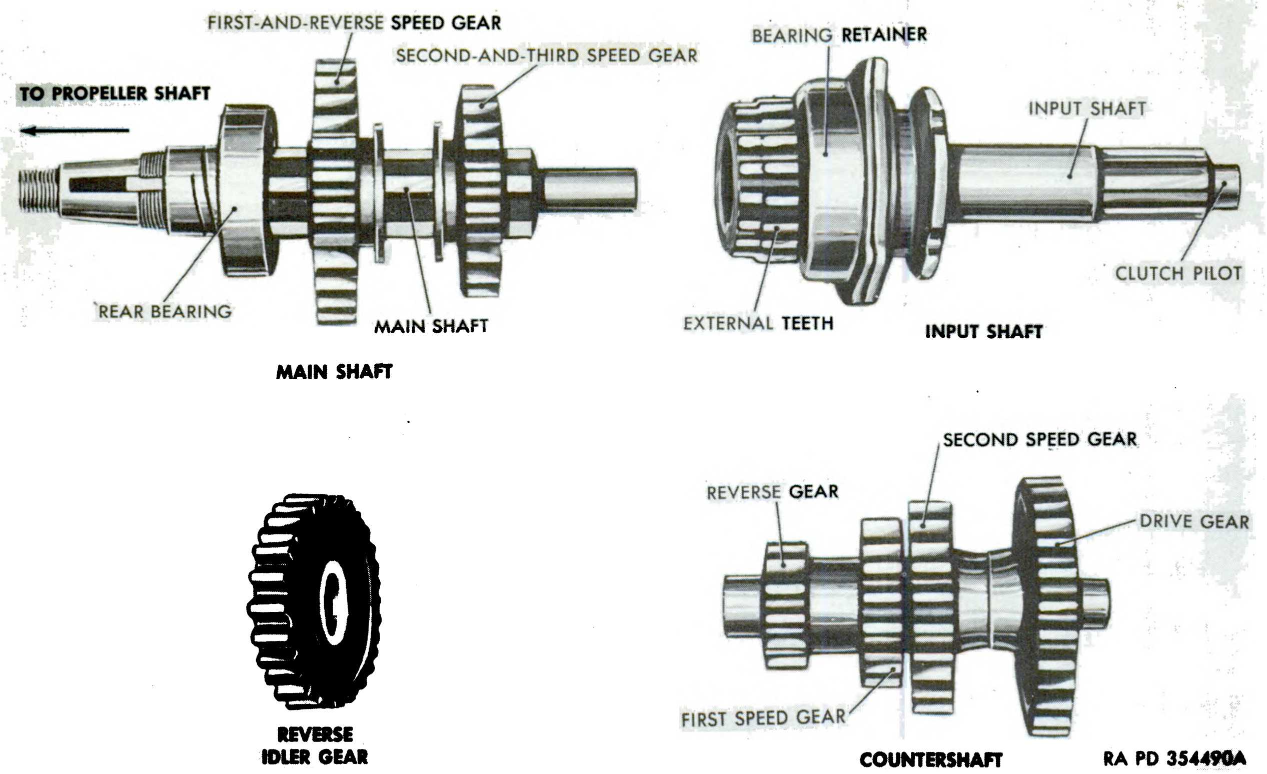

FIRST-AND-REVERSE SPEED GEAR
SECOND-AND-THIRD SPEED GEAR
TO PROPELLER SHAFT
REAR BEARING
MAIN SHAFT
MAIN SHAFT
BEARING RETAINER
INPUT SHAFT
CLUTCH PILOT
EXTERNAL TEETH
INPUT SHAFT
SECOND SPEED GEAR
REVERSE GEAR
DRIVE GEAR
FIRST SPEED GEAR
REVERSE IDLER GEAR
COUNTERSHAFT
RA PD 354490A

Figure 305. Principal gear groups of a three-speed selective system.

can be shifted forward to mesh with the countershaft first-speed gear or rearward to mesh with the reverse idler gear. The countershaft reverse gear is usually in constant mesh with the reverse idler gear. In some transmissions, the reverse idler gear is shifted to mesh with the countershaft reverse gear at the same time that the first-and-reverse speed main shaft gear is shifted to mesh with the reverse idler gear.

(3) *Other parts.* The main shaft, countershaft, and input shafts, with their respective gears, are mounted on antifriction bearings in the transmission case. Shift rails and forks are provided to move the gears when the control lever is moved by the driver to change speeds. The countershaft is generally placed below the main shaft. This permits a deep, narrow case, which retains a considerable quantity of oil without danger of leakage, since the oil level is maintained below the oil seals where the input shaft enters the case and the main shaft leaves it.

c. Transmission Positions.

(1) *Neutral.* In figure 306 the gears are shown in the neutral position. The input shaft drives the countershaft through the main drive gear and countershaft drive gear. None of the countershaft gears are in mesh with the main shaft sliding gears, however, so the main shaft is not driven. When the gears are in this position, there is no connection between the engine and the driving wheels, so the vehicle remains stationary while the engine is running. In the transmission shown in figure 306, the gear ratio between the main drive gear and the countershaft drive gear is about 1.5:1. Therefore, the countershaft rotates at approximately 0.7 times the speed of the input shaft or crankshaft. The path of transmitted power is shown by the arrows.

(2) *First speed.* When the gears are in first-speed position, the first-and-reverse speed main shaft gear is shifted forward to mesh with and be driven by the countershaft first-speed gear. The countershaft

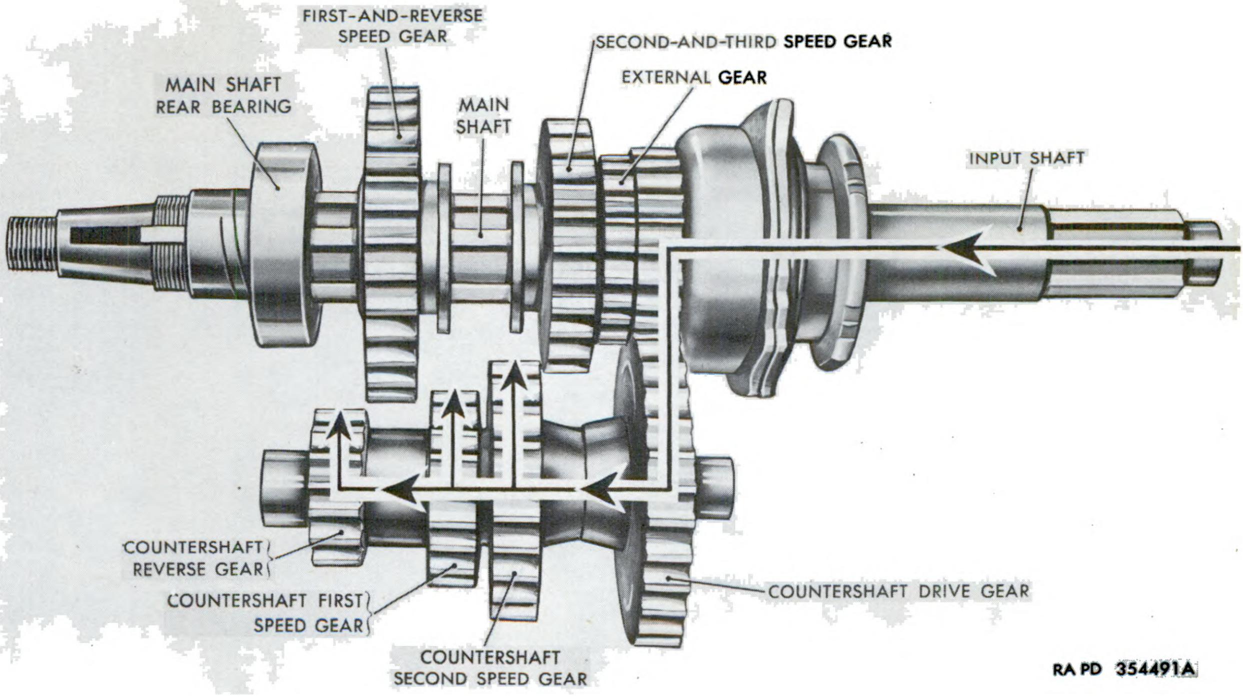

FIRST-AND-REVERSE SPEED GEAR
MAIN SHAFT REAR BEARING
MAIN SHAFT
SECOND-AND-THIRD SPEED GEAR
EXTERNAL GEAR
INPUT SHAFT
COUNTERSHAFT REVERSE GEAR
COUNTERSHAFT FIRST SPEED GEAR
COUNTERSHAFT SECOND SPEED GEAR
COUNTERSHAFT DRIVE GEAR
RA PD 354491A

Figure 306. Transmission gears in neutral position.

rotates at about 0.7 crankshaft speed. There is a further speed reduction between the countershaft first-speed gear (driving) and the first-and-reverse main shaft gear (driven) of about 1.5. Therefore, the crankshaft rotates 1.5 x 1.5, or 2.25 times for each turn of the propeller shaft, thus increasing the torque on the output shaft by 2.25 : 1.

(3) *Second speed.* The second-speed position is shown in figure 307. In passing from first speed to second speed, both sliding gears have been shifted rearward; the first-and-reverse speed main shaft gear has been shifted out of engagement into the neutral position and the second-and-third speed main shaft gear has been shifted into mesh with the countershaft second-speed gear. The input shaft, through its integral main drive gear, is now driving the countershaft through the countershaft drive gear (as is the case in all speeds), and the countershaft is driving the main shaft through the countershaft second-speed gear and the second-and-third speed main shaft gear as shown by the arrows (fig. 307). Since the countershaft second-speed gear and the second-and-third speed main shaft gear are the same size, their gear ratio is 1 : 1. This means that the main shaft rotates at the same speed as the countershaft; that is, the engine crankshaft makes about 1.5 revolutions to one of the propeller shaft.

(4) *Third speed.* The third-speed, or direct-drive, position of the gears is shown in figure 308. In passing from second speed to third speed, the second-and-third speed main shaft gear has been shifted forward, causing the internal teeth in this gear to engage the external teeth on the main drive gear. A device of this kind, with internal teeth on one member that mesh or engage with external teeth on another member, is often called a *dog clutch,* or clutch gear. It makes a direct connection between the input shaft and main shaft as shown by the arrows (fig. 308). The propeller shaft therefore rotates at crankshaft speed.

(5) *Reverse.* The reverse position of the gears is shown in figure 309. To better

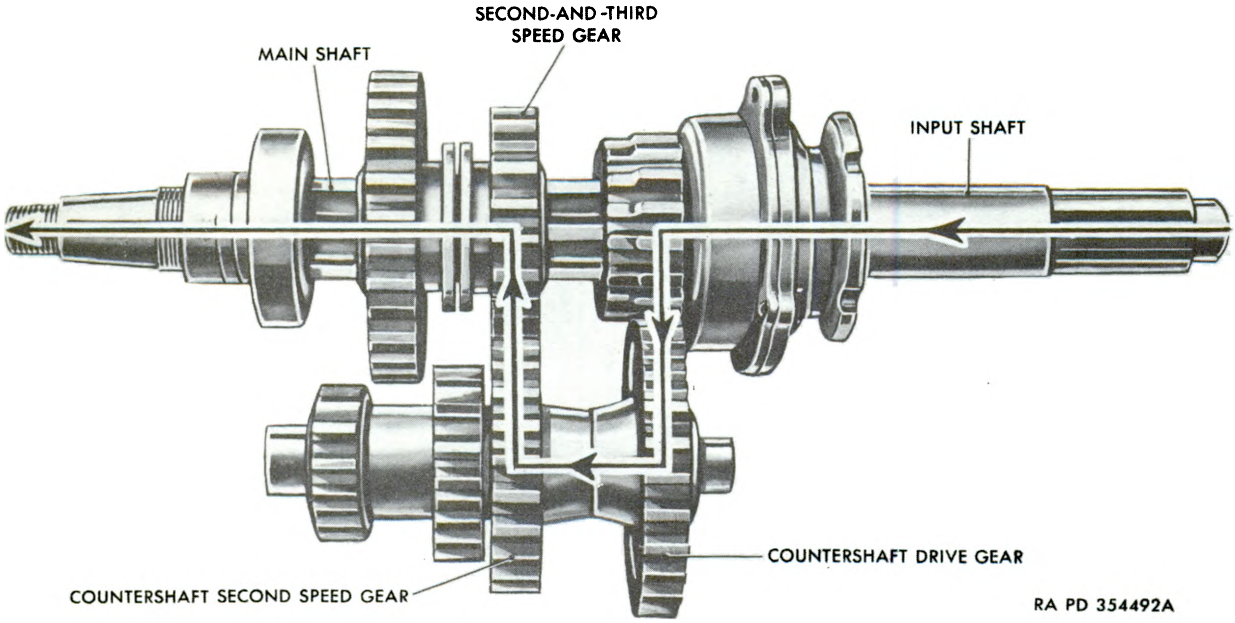

SECOND-AND -THIRD SPEED GEAR
MAIN SHAFT
INPUT SHAFT
COUNTERSHAFT DRIVE GEAR
COUNTERSHAFT SECOND SPEED GEAR
RA PD 354492A

Figure 307. Transmission gears in second-speed position.

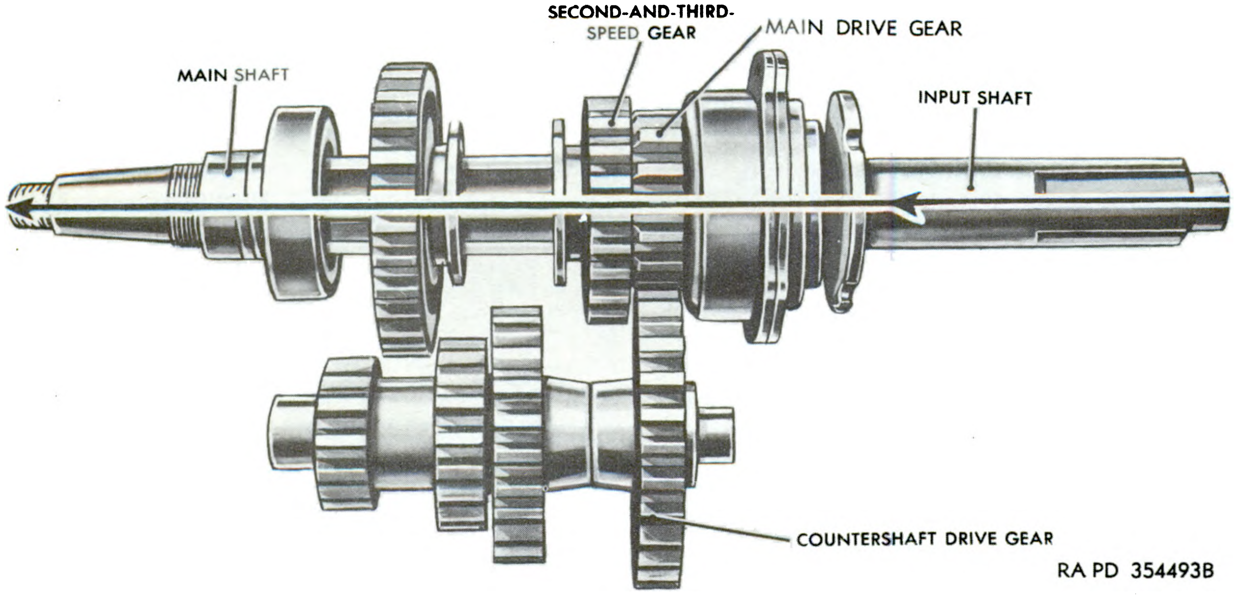

SECOND-AND-THIRD-SPEED GEAR
MAIN DRIVE GEAR
MAIN SHAFT
INPUT SHAFT
COUNTERSHAFT DRIVE GEAR
RA PD 354493B

Figure 308. Transmission gears in third-speed or direct-drive position.

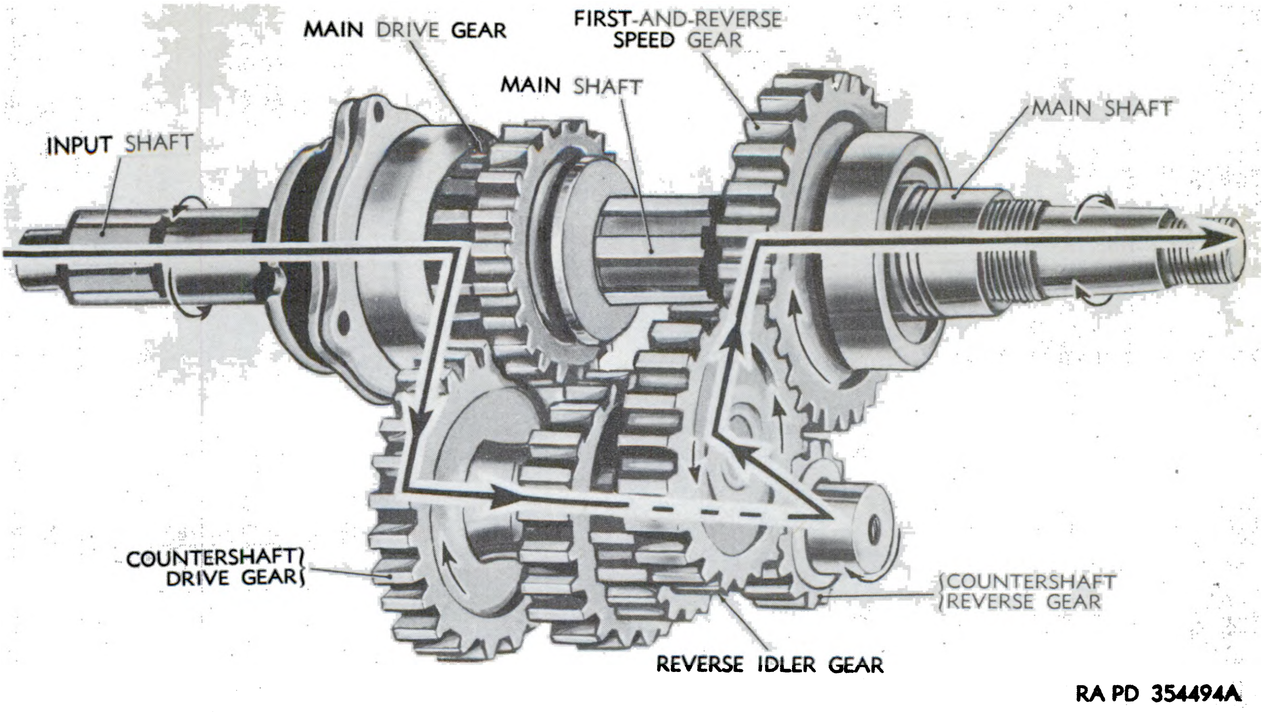


Figure 309. Transmission gears in reverse speed position.

illustrate the reverse idler gear, the parts have been turned end for end, and are shown from the opposite side from previous illustrations (figs. 305 through 308). In passing from neutral to reverse, the first-and-reverse speed main shaft gear has been shifted rearward to mesh with the reverse idler gear. The sole function of this gear is to make the main shaft rotate in the opposite direction to the input shaft, as shown by the short, heavy arrows; it does not influence the gear ratio between the countershaft reverse gear and the first-and-reverse speed main shaft gear. The gear ratio between these gears is about 2. In reverse, the crankshaft rotates 1.5 x 2, or 3 times for every revolution of the propeller shaft.

d. Helical Gears. For the purpose of simplicity, the transmission described in *c* above is of the spur-gear type. In modern practice, however, helical gears are widely used because they run more quietly than spur gears. There is a side thrust on a helical gear, due to the angularity of the teeth, which tends to slide the gears out of mesh. This difficulty is avoided in constant-mesh transmissions because the gears do not slide on the shaft. When sliding helical gears are employed in a transmission, the splines on which they slide are also cut helically to the same angle as the teeth; this offsets the side thrust.

e. Transmission Controls.

(1) The three-speed selective transmission described in *a* and *b* above is operated by a control level assembled to, and extending from, the control housing (fig. 310). The lever has a ball fulcrum fitting into a socket in the housing. It is kept from rotating by a setscrew entering a slot in the side of the ball fulcrum but is free to move backward, forward, and sidewise. The end of the level below the ball fulcrum engages both slots, but there is an interlock device (usually a ball or pin engaging notches in each shifter shaft) that permits one shifter shaft to move at a time, but not both. This prevents two speeds being engaged at once. When the control lever handle is pressed to the left, the slot in the first-and-reverse shifter shaft is engaged and the fork can be moved backward or forward. After the first-and-reverse shifter shaft has been returned to the neutral position, the control lever can be pressed to the right and the second-and-third shifter shaft and fork

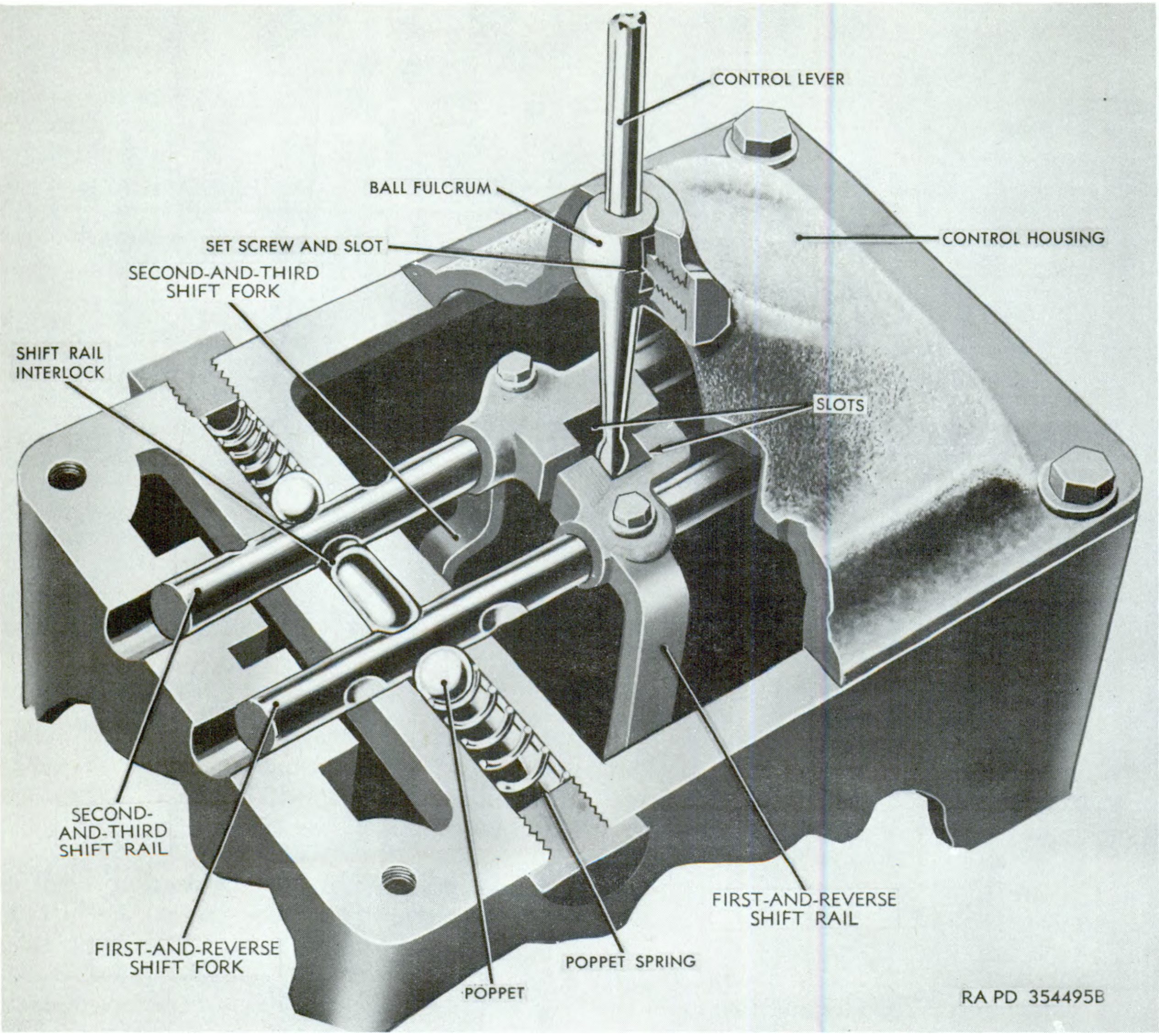

CONTROL LEVER
BALL FULCRUM
CONTROL HOUSING
SET SCREW AND SLOT
SECOND-AND-THIRD SHIFT FORK
SHIFT RAIL INTERLOCK
SLOTS
SECOND-AND-THIRD SHIFT RAIL
FIRST-AND-REVERSE SHIFT RAIL
FIRST-AND-REVERSE SHIFT FORK
POPPET SPRING
POPPET
RA PD 354495B

Figure 310. Transmission shifting mechanism and control lever.

can be moved forward or backward. The shifter shafts are held in the different speeds and the neutral position by spring-loaded balls or poppets engaging notches in the shifter shafts.

(2) Since 1939, the transmission control levers on the steering column have come into general use. These are generally used with the synchromesh transmissions, and are described in paragraph 201.

201. Constant-Mesh and Synchromesh Transmissions

a. Purpose. Sliding-gear transmissions use stub-tooth gears for easy engagement; consequently, the transmission is usually noisy when operating in the intermediate speeds. In recent years, the conventional sliding-gear transmission has been superseded, particularly on passenger vehicles, by systems in which the gears are always in mesh with their mates, and selection is made by sliding other components into and out of connection. Two of the most common of these systems are the constant-mesh and the synchromesh, which has an additional feature to prevent clashing of gears.

b. Constant-Mesh Transmissions.

(1) In this type of transmission (fig. 311) certain of the countershaft gears are constantly in mesh with gears on the main

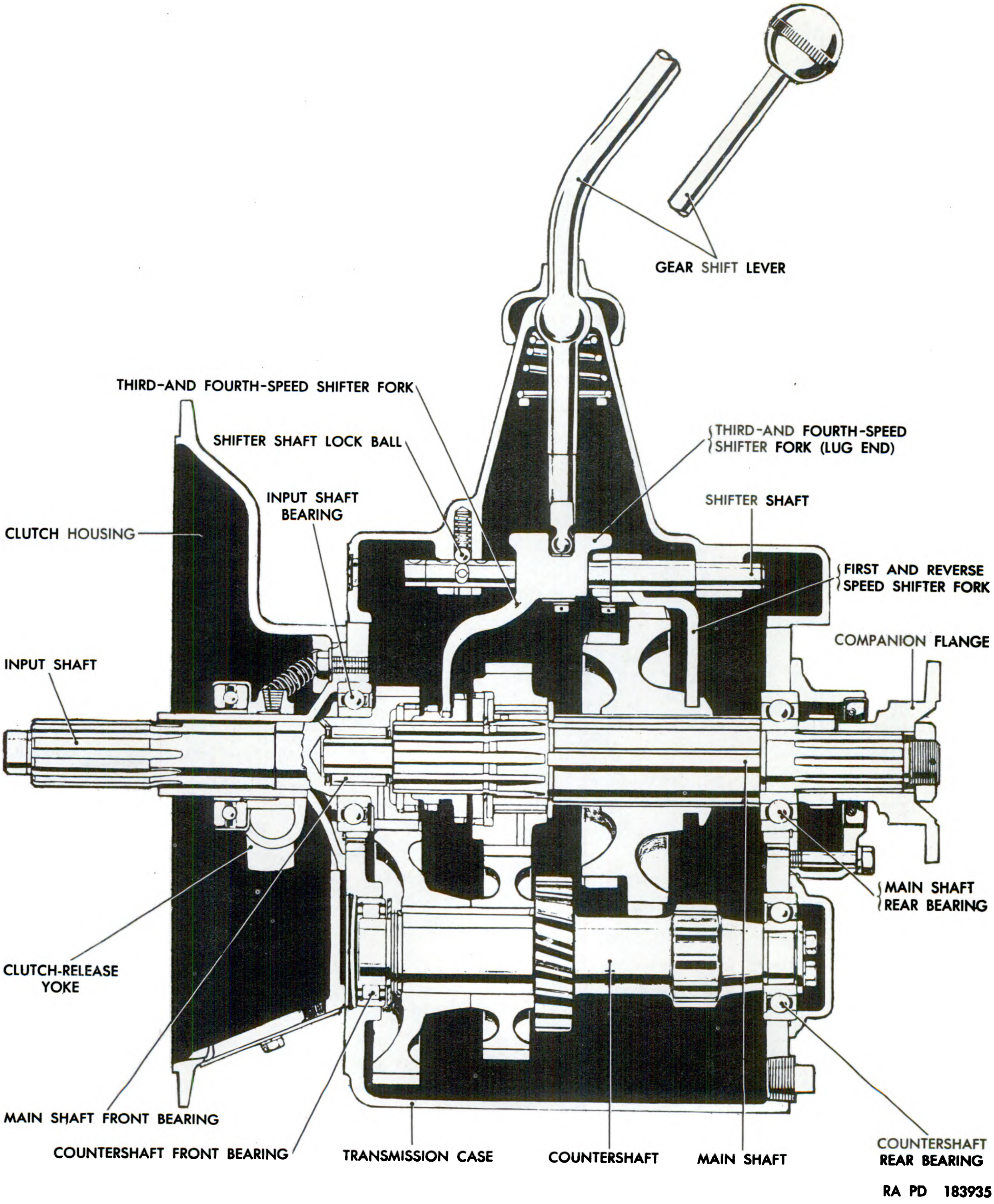

GEAR SHIFT LEVER
THIRD-AND FOURTH-SPEED SHIFTER FORK
SHIFTER SHAFT LOCK BALL
THIRD-AND FOURTH-SPEED SHIFTER FORK (LUG END)
INPUT SHAFT BEARING
SHIFTER SHAFT
CLUTCH HOUSING
FIRST AND REVERSE SPEED SHIFTER FORK
COMPANION FLANGE
INPUT SHAFT
MAIN SHAFT REAR BEARING
CLUTCH-RELEASE YOKE
MAIN SHAFT FRONT BEARING
COUNTERSHAFT FRONT BEARING
TRANSMISSION CASE
COUNTERSHAFT
MAIN SHAFT
COUNTERSHAFT REAR BEARING
RA PD 183935

Figure 311. Constant-mesh transmission assembly—cross sectional view.

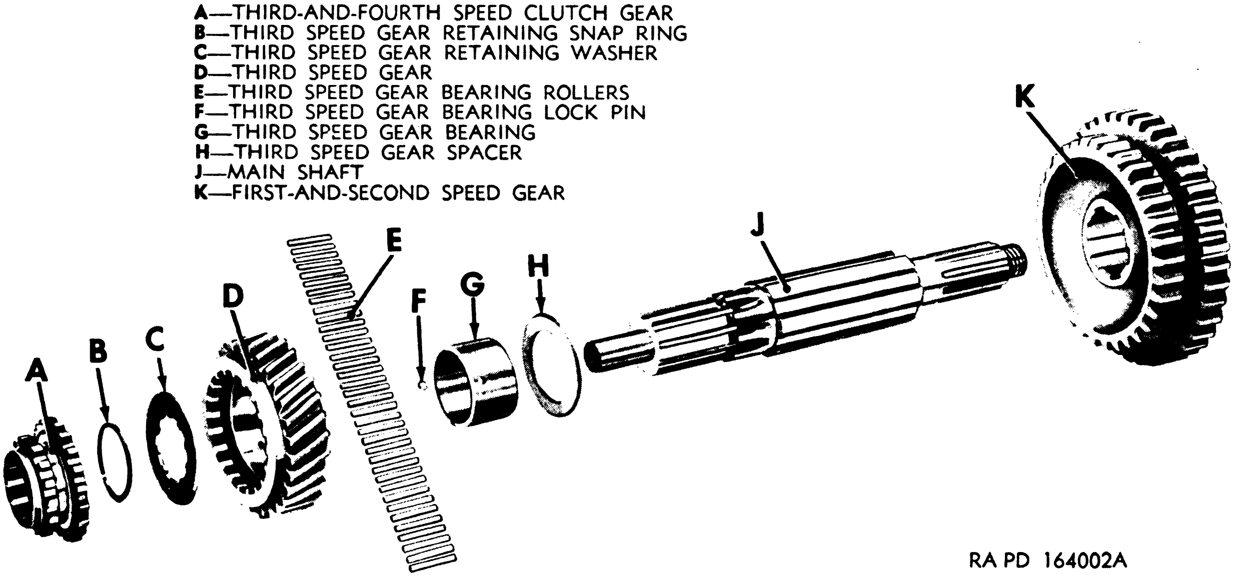

A—THIRD-AND-FOURTH SPEED CLUTCH GEAR
B—THIRD SPEED GEAR RETAINING SNAP RING
C—THIRD SPEED GEAR RETAINING WASHER
D—THIRD SPEED GEAR
E—THIRD SPEED GEAR BEARING ROLLERS
F—THIRD SPEED GEAR BEARING LOCK PIN
G—THIRD SPEED GEAR BEARING
H—THIRD SPEED GEAR SPACER
J—MAIN SHAFT
K—FIRST-AND-SECOND SPEED GEAR
K
J
E
H
G
D
F
C
B
A
RA PD 164002A

Figure 312. Main shaft assembly—disassembled view.

shaft. The meshing gears on the main shaft are fixed so they cannot move endwise, but they are supported on roller bearings so they can rotate independently of the main shaft. For example, the main shaft assembly of the transmission shown in figure 311 is illustrated in figure 312 in disassembled view. Note that the main shaft third-speed gear (D, fig. 312) is supported on the shaft by bearing rollers (E, fig. 312). Note also that this gear has internal teeth that match external teeth on the main shaft third- and fourth-speed clutch gear (A, fig. 312). Usually, helical gears are used in this type transmission.

(2) The transmission shown in figure 311 has four forward speeds. When a shift is made to third, the third- and fourth-speed shifter fork moves the clutch gear (A, fig. 312) toward the third-speed gear (D, fig. 312). The external teeth of the clutch gear are thus meshed with the internal teeth in the third-speed gear. Since the third-speed gear is rotating (it being meshed with a rotating countershaft gear), the clutch gear must now also turn. The clutch gear is splined to the main shaft (J, fig. 312), so the main shaft also must rotate as the clutch gear is turned.

(3) When a shift is made to fourth, or direct, speed, the clutch gear is moved toward the driving gear on the input shaft. External teeth on the clutch gear mesh with internal teeth in the driving gear so the clutch gear is driven at the same speed as the driving gear. Since the clutch gear is splined to the main shaft, the main shaft is also driven at this speed.

(4) Constant-mesh gears are seldom used for all speeds. Common practice is to use such gears for the higher gears, with sliding gears for first- and reverse-speed, or for reverse only.

c. *Synchromesh Transmissions.*

(1) The synchromesh transmission is a type of constant-mesh transmission that permits gears to be selected without clashing, by synchronizing the speeds of mating parts before they engage. It employs a combination metal-to-metal friction cone clutch and a dog or gear positive clutch to engage the main drive gear and second-speed main shaft gear with the transmission main shaft. The friction cone clutch engages first, bringing the driving and driven members to the same speed, after which the dog clutch engages easily without clashing. This process is accomplished in one continuous operation when the driver declutches and

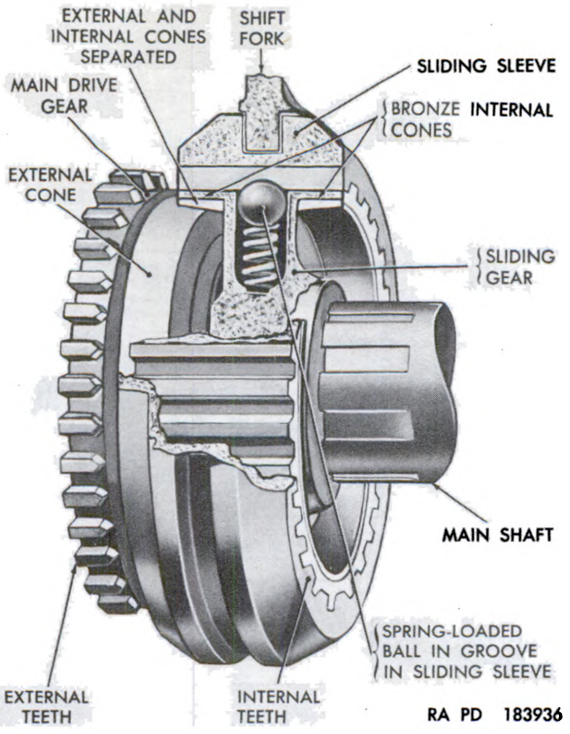

EXTERNAL AND INTERNAL CONES SEPARATED
SHIFT FORK
MAIN DRIVE GEAR
SLIDING SLEEVE
BRONZE INTERNAL CONES
EXTERNAL CONE
SLIDING GEAR
MAIN SHAFT
SPRING-LOADED BALL IN GROOVE IN SLIDING SLEEVE
EXTERNAL TEETH
INTERNAL TEETH
RA PD 183936

Figure 313. Synchromesh clutch—disengaged.

moves the control lever in the usual manner. The construction of synchromesh transmissions varies somewhat with different manufacturers, but the principle is the same in all.

(2) The construction of a popular syncromesh clutch is shown in figure 313. The driving member consists of a sliding gear splined to the transmission main shaft with bronze internal cones on each side. It is surrounded by a sliding sleeve having internal teeth that are meshed with the external teeth of the sliding gear. The sliding sleeve is grooved around the outside to receive the shift fork. Six spring-loaded balls in radially-drilled holes in the gear fit into an internal groove in the sliding sleeve and prevent it from moving endwise relative to the gear until the latter has reached the end of its travel. The driven members are the main drive gear and second-speed main shaft gear, each of which has external cones and external teeth machined on its sides to engage the internal cones of the sliding gear and the internal teeth of the sliding sleeve. The synchromesh clutch is shown disengaged in figure 313 and engaged in figure 314.

(3) The synchromesh clutch operates as follows: when the transmission control lever is moved by the driver to the third-speed or direct-drive position, the shift fork moves the sliding gear and sliding sleeve forward as a unit until the internal cone on the sliding gear engages the external cone on the main drive gear. This action brings the two gears to the same speed and stops endwise travel of the sliding gear. The sliding sleeve then slides over the balls and silently engages the external teeth on the main drive gear, locking the main drive gear and transmission main shaft together as shown in figure 314. When the transmission control lever is shifted to the second-speed position, the sliding gear and sleeve move rearward and the same action takes place, locking the transmission main shaft to the second-speed main shaft gear. The synchromesh clutch is not applied to first

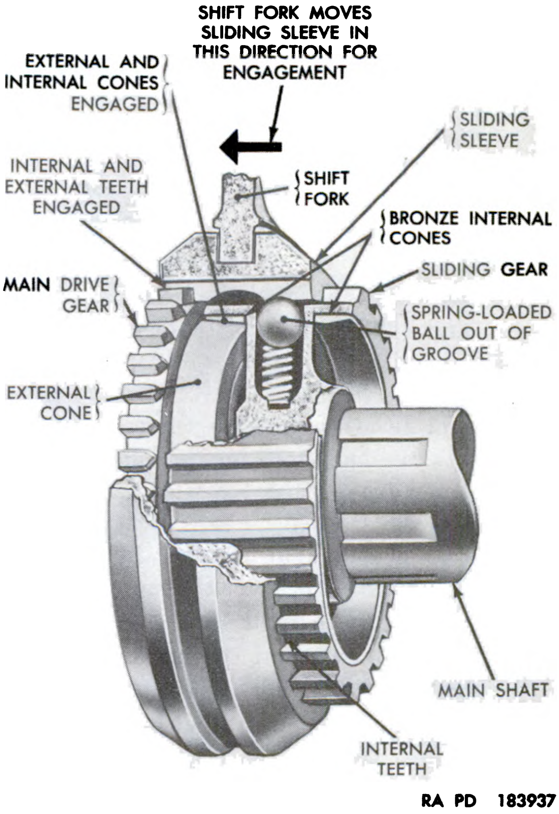

SHIFT FORK MOVES SLIDING SLEEVE IN THIS DIRECTION FOR ENGAGEMENT
EXTERNAL AND INTERNAL CONES ENGAGED
SLIDING SLEEVE
INTERNAL AND EXTERNAL TEETH ENGAGED
SHIFT FORK
BRONZE INTERNAL CONES
SLIDING GEAR
MAIN DRIVE GEAR
SPRING-LOADED BALL OUT OF GROOVE
EXTERNAL CONE
MAIN SHAFT
INTERNAL TEETH
RA PD 183937

Figure 314. Synchromesh clutch—engaged.

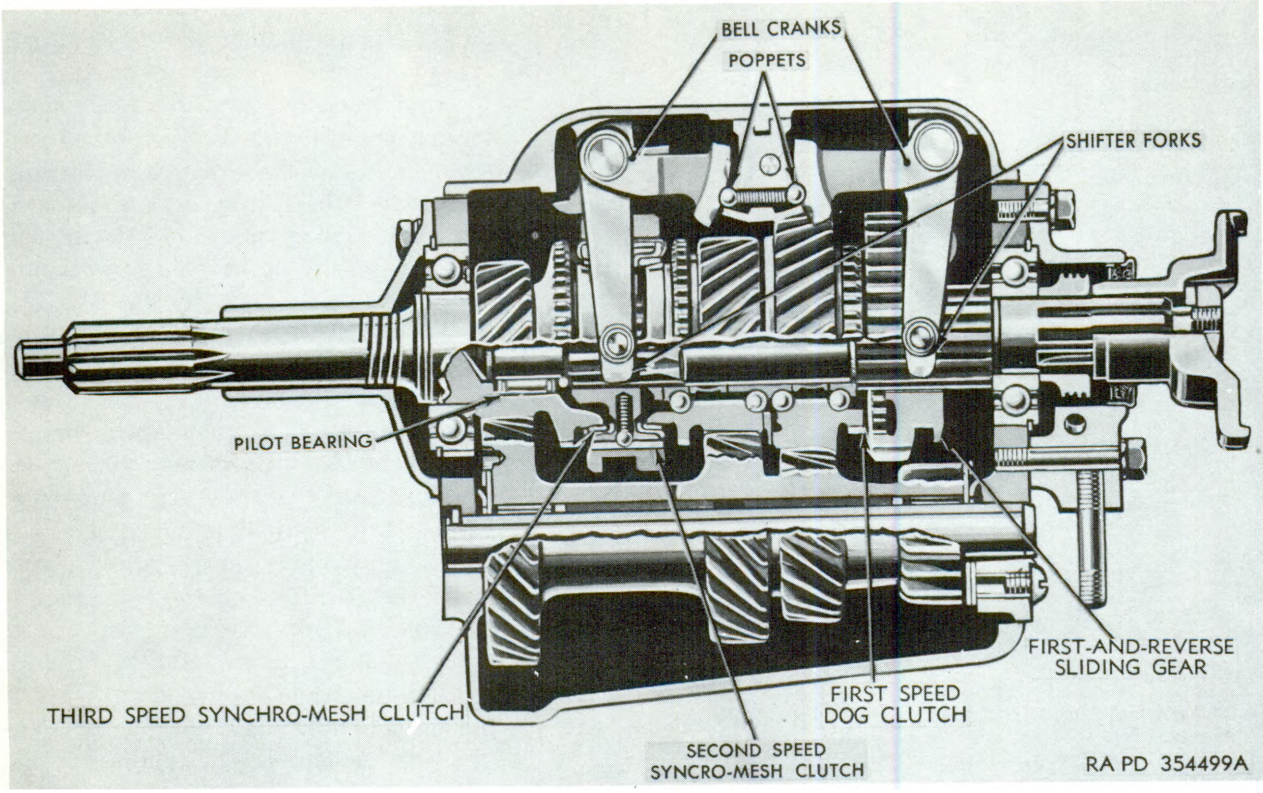

BELL CRANKS
POPPETS
SHIFTER FORKS
PILOT BEARING
FIRST-AND-REVERSE SLIDING GEAR
FIRST SPEED DOG CLUTCH
THIRD SPEED SYNCHRO-MESH CLUTCH
SECOND SPEED SYNCRO-MESH CLUTCH
RA PD 354499A

Figure 315. Synchromesh transmission arranged for steering column control.

speed or to reverse. First speed is engaged by an ordinary dog clutch when constant mesh is employed, or by a sliding gear; reverse is always engaged by means of a sliding gear. Figure 315 shows a synchromesh transmission in cross section which uses constant-mesh helical gears for the three forward speeds and a sliding spur gear for reverse.

(4) Some transmissions are controlled by a steering column control lever (fig. 316). The positions for the various speeds are the same as those for the vertical control lever except that the lever is horizontal. The shifter forks are pivoted on bell-cranks which are turned by a steering column control lever through the linkage shown. The poppets shown in figure 315 engage notches at the inner end of each bell crank. Other types of synchromesh transmissions controlled by steering column levers have shifter shafts and forks moved by a linkage similar to those used with a vertical control lever.

(5) Transmissions in a limited number of heavy duty trucks are not equipped with synchromesh gears. To insure engagement without clashing, double-clutching is usually employed by the driver.

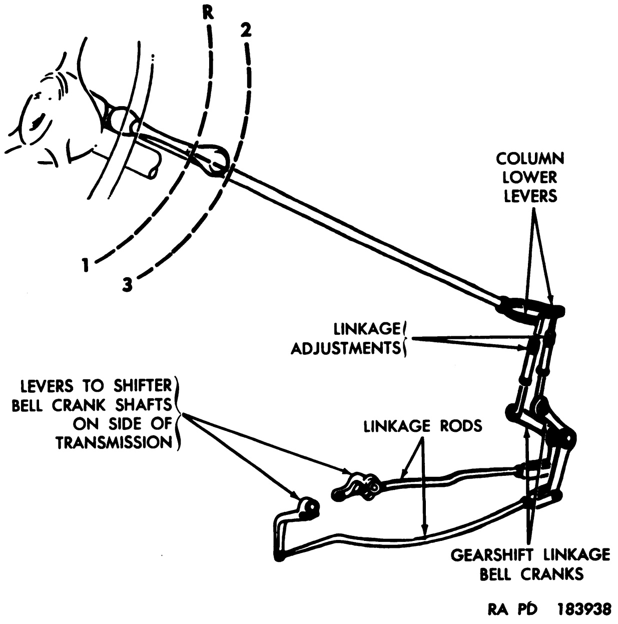

R
2
1
3
COLUMN LOWER LEVERS
LINKAGE ADJUSTMENTS
LEVERS TO SHIFTER BELL CRANK SHAFTS ON SIDE OF TRANSMISSION
LINKAGE RODS
GEARSHIFT LINKAGE BELL CRANKS
RA PD 183938

Figure 316. Steering column transmission control lever and linkage.

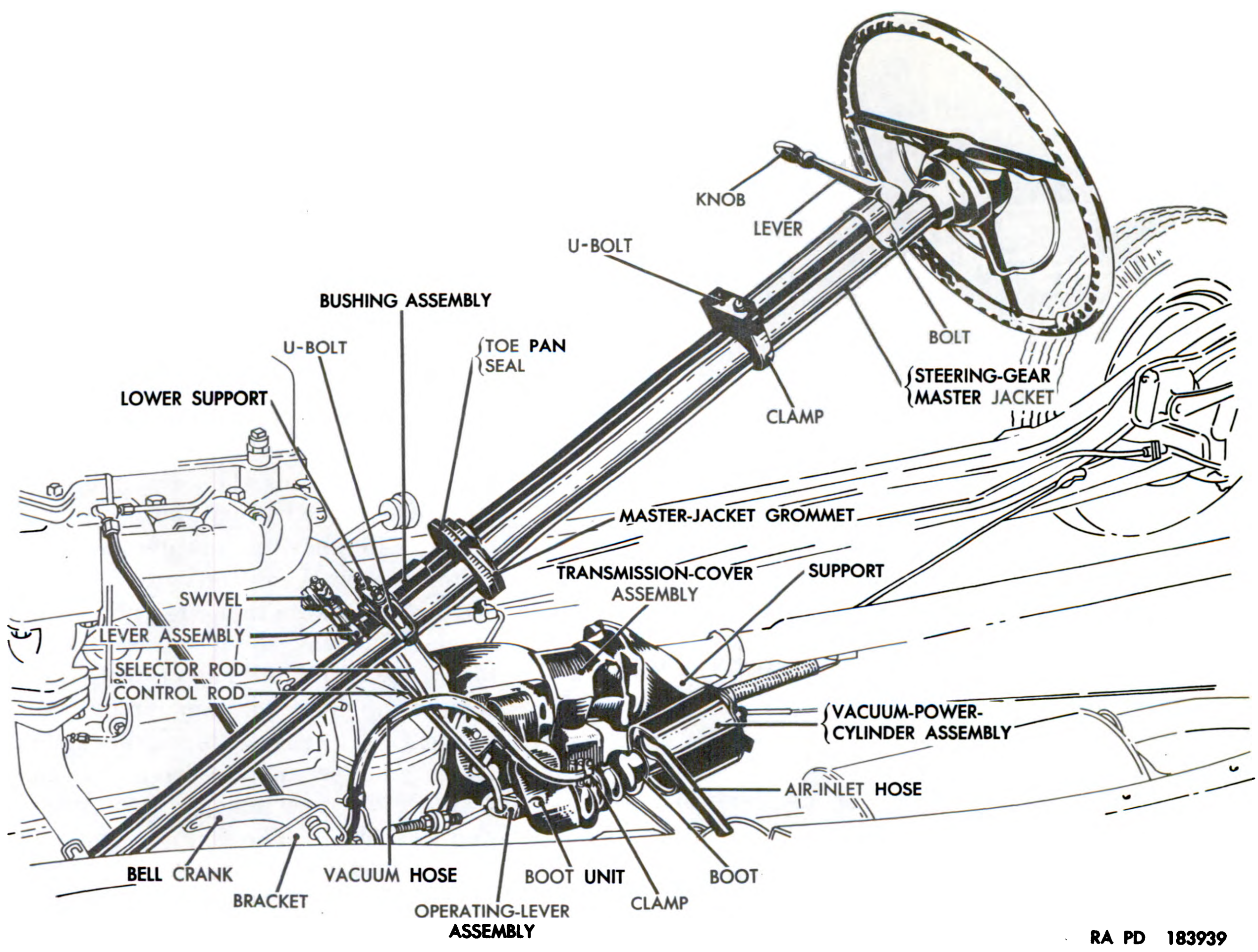

KNOB
LEVER
U-BOLT
BUSHING ASSEMBLY
U-BOLT
TOE PAN SEAL
LOWER SUPPORT
BOLT
STEERING-GEAR MASTER JACKET
CLAMP
MASTER-JACKET GROMMET
TRANSMISSION-COVER ASSEMBLY
SUPPORT
SWIVEL
LEVER ASSEMBLY
SELECTOR ROD
CONTROL ROD
VACUUM-POWER-CYLINDER ASSEMBLY
AIR-INLET HOSE
BELL CRANK
BRACKET
VACUUM HOSE
BOOT UNIT
OPERATING-LEVER ASSEMBLY
CLAMP
BOOT
RA PD 183939

Figure 317. Steering column shift lever, using vacuum-power shifter device.

202. Gearshift Assisters

a. General. Various devices have been used to assist in gearshifting. Some of these employed solenoids to shift gears electrically when the driver selected the desired gear ratio by means of a button or lever. Others used the engine intake manifold vacuum to actuate a shifting mechanism that supplied most of the shifting effort; with these, the driver operated a shift lever but was required to supply only a small part of the effort required to shift gears. Still other devices provided gearshifting when the engine and car speeds were correct for shifting and the driver momentarily released the accelerator pedal. Most of these devices have been discarded since the introduction of automatic transmissions using torque converters or fluid couplings. Some of the automatic transmissions have a selective feature that permits the driver to select one range or another by manipulation of the accelerator pedal when the vehicle and engine speeds are within the selective range (pars. 203 and 204).

b. Vacuum Assist. An earlier model passenger car used a vacuum-power shifter device, as shown in figures 317 and 318. The gearshift lever is moved in the usual manner. The first movement (in a direction parallel to the steering column) selects the shift fork in the transmission (either the first-and-reverse fork or the second-and-third fork). The second movement (parallel to the steering wheel) causes the vacuum-power cylinder to come into action. The vacuum-power cylinder has a piston centered in a cylinder (fig. 318). The piston is connected by a hollow shaft to the shift lever through linkage. When the shift lever is moved for gearshifting, an inner hollow shaft which is connected to the intake manifold is moved by a secondary link to the shift lever linkage. This movement is sufficient to operate the sleeve valve centered in the piston. A vacuum connection

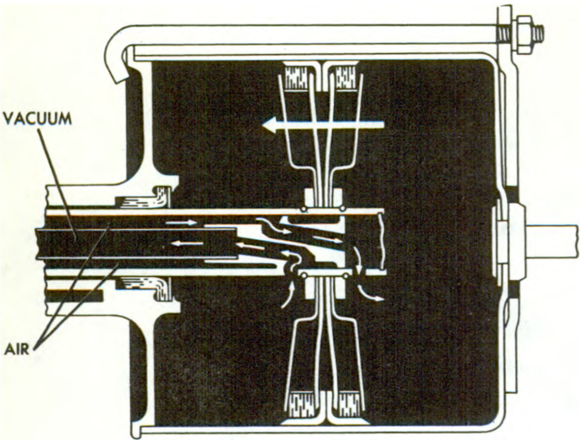


Figure 318. Vacuum cylinder in sectional view, showing position of valve and direction of piston movement when shifting into reverse or second is underway.

is made to one side of the piston while air is admitted to the other. The piston therefore is forced to move. This movement is carried through the shaft on which the piston is mounted to the shifting linkage, thereby causing the shift fork to move and produce shifting. In the illustration (fig. 318), vacuum-power cylinder action is shown when a shift into reverse or second speed is under way.

c. *Automatic Transmissions.* Some passenger cars with a fluid coupling or torque converter use a semiconventional transmission with four forward speeds, and with special controls for providing upshifting or downshifting in certain speed ranges when the accelerator pedal is momentarily released. The special controls include a governor, solenoid, kickdown switch, and antistall control as shown in figure 319. The power for shifting comes from oil pressure acting in a special piston-cylinder combination in the transmission. In this system, the driver must first select either the low range or the high range. In the low range, the system would select either first or second gear, and in high range either third or fourth gear, the selection being made according to vehicle and engine speeds and throttle movement.

(1) *Action during upshift.* As vehicle speed increases, the governor turns faster and faster and, at somewhere above 14 mph (when in third speed), the governor opens its contacts. This opens the solenoid circuit, causing the solenoid to release its plunger. This action closes a valve that causes oil pressure to be directed into the cylinder. The oil pressure then moves the piston in the cylinder to the left, spring-loading the shifter fork. When the driver momentarily releases the accelerator pedal, driving pressure through the transmission gears is momentarily relieved. This permits the spring pressure to move the shift lever so as an upshift is made. In the low range, the upshift is from first to second. In the high range, the upshift is from third to fourth.

(2) *Action during downshift.* When the car slows down to a certain minimum speed, the governor will close its contacts. When this happens, the solenoid becomes connected to the battery and it opens the oil valve to relieve the oil pressure on the piston. Now, the piston moves back into the position shown in figure 319. As it so moves, a ridge on the piston rod momentarily opens the interrupter switch, thus interrupting the ignition circuit for a moment. The engine stops firing and delivering power, and the driving pressure through the transmission gears is momentarily relieved. The spring pressure can return the shift fork to the downshifted position. In the low range, the downshift is from second to first speed. In the high range, the downshift is from fourth to third speed.

(3) *Kickdown.* The kickdown switch provides a means of downshifting above the normal actuating speeds by pushing all the way down on the accelerator pedal. This action closes the switch, directly connecting the solenoid to the battery so that the sequence of events described in (2) above will follow.

(4) *Antistall control.* The antistall control acts to prevent excessively rapid closing of the throttle and consequent stalling of the engine. It contains a small solenoid which operates a ball check valve. At low speeds, when the governor contacts are closed, the solenoid is energized through the contacts and it holds the ball check valve closed. A dashpot arrangement in the control can operate to cushion throttle closing and prevent the throttle from closing too rapidly. At higher

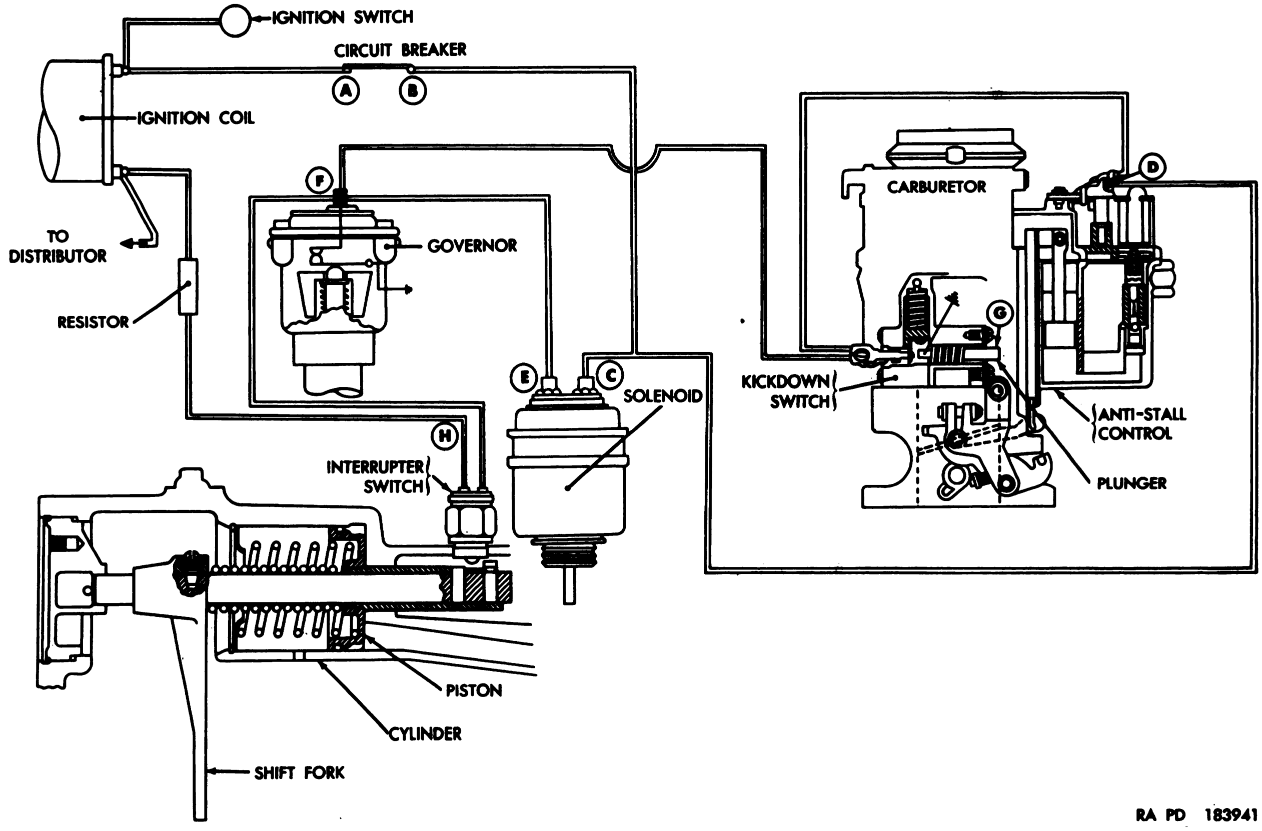


Figure 319. Control system for achieving upshift or downshift in automatic transmissions.

speeds, where there is no danger of stalling, the control is automatically eliminated by the opening of the governor contacts. This opens the solenoid, which then allows the ballcheck valve to open so the dashpot cannot operate.

Section II. HYDRAMATIC AND TORQUE CONVERTER TRANSMISSIONS

203. Hydramatic Transmission

a. General. The hydramatic transmission (figs. 299 and 320) consists of a fluid coupling (par. 195) and an automatic transmission having four speeds forward and one reverse. In some vehicles, no reverse gearing is incorporated in the transmission as this is provided in the transfer assembly. Slippage in the fluid coupling at engine idling speeds provides the cushioning action of a clutch. Gear changes are made automatically by hydraulic pressure and are governed by the speed of the vehicle and the extent to which the driver depresses the accelerator.

b. Power Transmitting Units. The hydramatic transmission consists of the following power transmitting units, listed in the order in which they transmit the power: the flywheel cover; the front planetary unit, consisting of single reduction planetary gears; the fluid coupling or torus members; and the rear planetary unit, also consisting of single-reduction planetary gears. The output shaft is connected to the rear planet carrier.

c. Planetary Units. The planetary units consist of planet gears (four in the front unit and six in the rear unit) which encircle and are meshed with the center, or sun, gear. These gears are, in turn, surrounded by a gear having internal teeth. One member of this planetary unit can be kept from rotating by a band wrapped around an integral drum. The band is applied or released by a servo mechanism which is merely a double-acting piston and cylinder operated by spring and oil pressure. Each unit also includes a multiple-disk clutch which is applied by oil pressure and released by spring pressure. When the clutch is released and the band applied, the planet gears are forced by the driving gear to

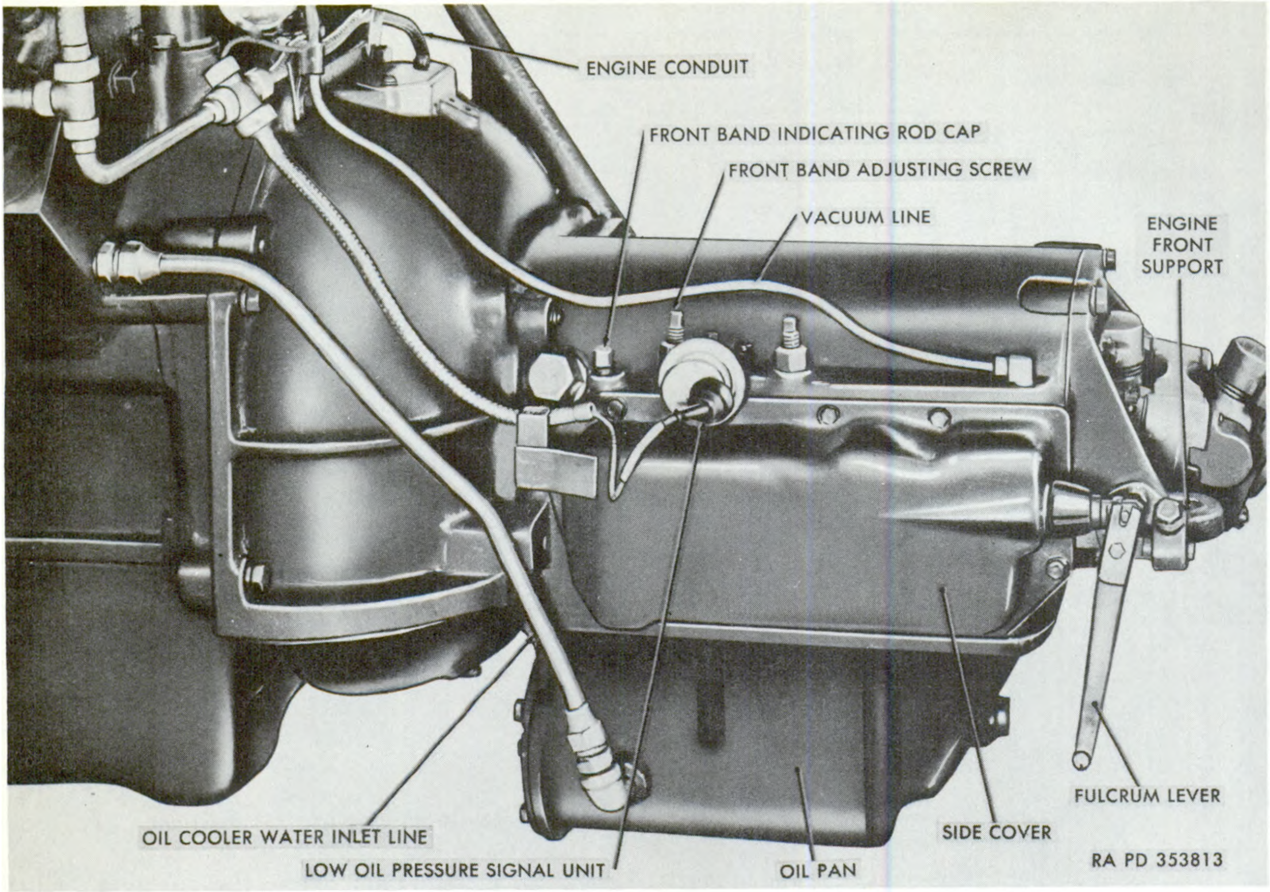
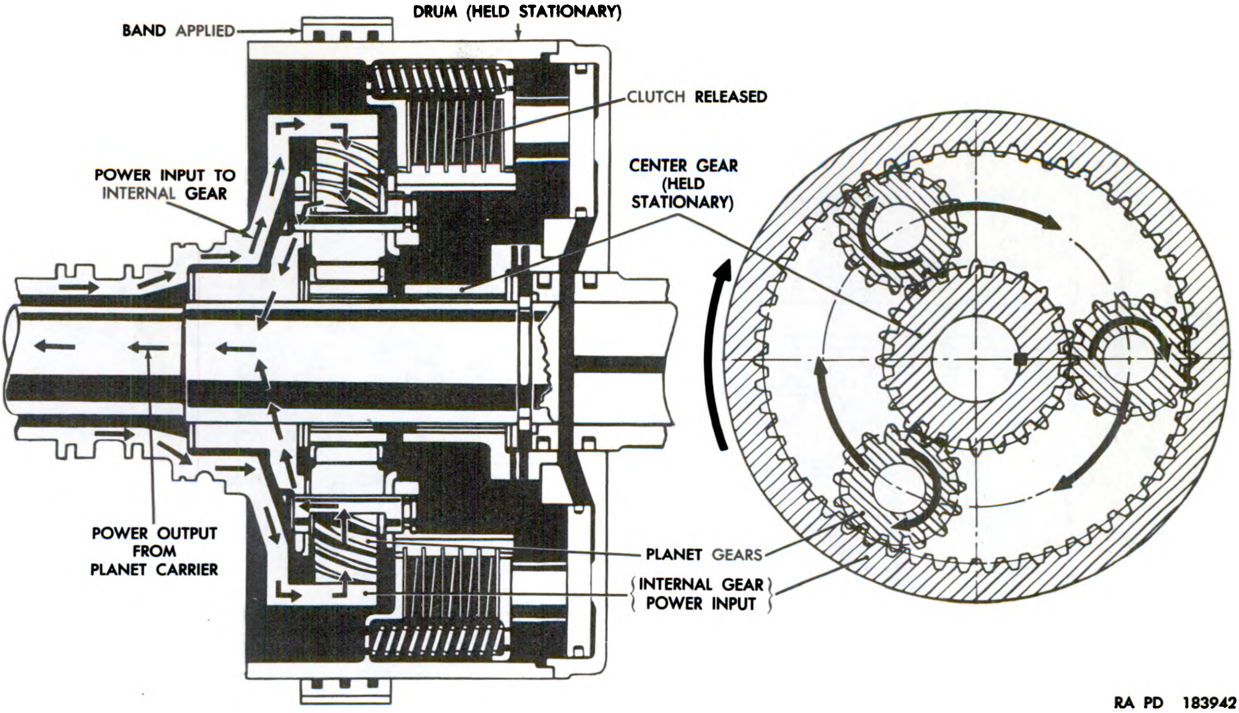

ENGINE CONDUIT
FRONT BAND INDICATING ROD CAP
FRONT BAND ADJUSTING SCREW
VACUUM LINE
ENGINE FRONT SUPPORT
FULCRUM LEVER
SIDE COVER
OIL PAN
OIL COOLER WATER INLET LINE
LOW OIL PRESSURE SIGNAL UNIT
RA PD 353813

Figure 320. Hydramatic transmission (without reverse speed).

"walk around" the stationary gear; consequently the output shaft, which is connected to the planet gears, is driven at reduced speed and the unit is in reduction (fig. 321). When the band is released and the clutch applied, the entire unit is locked together and rotates as a unit, providing direct drive (fig. 322). Each planetary unit is a complete two-speed transmission in itself, as it can operate either in reduction or direct drive. The transmission contains two of these planetary units. Refer to paragraph 187*e* for an explanation of planetary gear action.

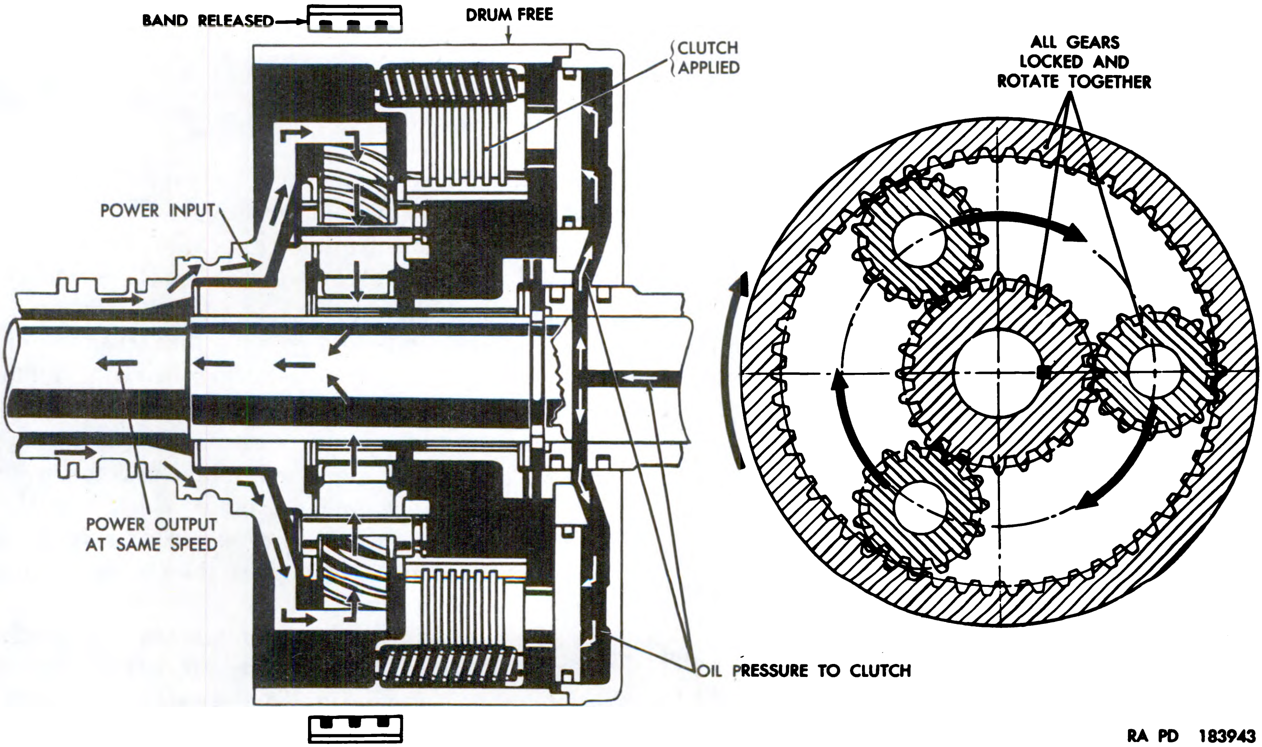
d. Hydraulic Control Units. The hydraulic control units include two oil pumps, two servos that operate the bands, a governor assembly, and a master control-valve assembly that controls the hydraulic oil pressure to the various control units. The speeds at which the gear changes occur are controlled by oil pressure to the control-valve mechanism. Briefly, this mechanism consists of balanced shift valves against which oil pressure is exerted at one end in proportion to throttle opening, and at the other end by pressure from the centrifugal governor, which is in direct proportion to the speed of the vehicle. When the vehicle reaches a certain point in relation to governor pressure and throttle opening, the transmission upshifts to a higher speed. When the vehicle speed decreases due to brake action or ascending a hill, a point is reached when the various pressures cause the transmission to shift to a lower gear. As throttle opening follows engine torque very closely, it controls the shift valve positioning in accordance with the demands for power made by the driver.

e. Gear Ratio. The four transmission speed ranges are secured as follows: in first speed, both planetary units are in reduction for a total ratio of 3.92:1; in second speed, the front unit is in direct drive and the rear unit in reduction for a ratio of 2.53:1; in third speed, the front unit is in reduction and the rear unit in direct drive for a ratio of 1.55:1; in fourth speed, both units are in direct drive. Figures 323 through 328 show


BAND APPLIED
DRUM (HELD STATIONARY)
CLUTCH RELEASED
POWER INPUT TO INTERNAL GEAR
CENTER GEAR (HELD STATIONARY)
POWER OUTPUT FROM PLANET CARRIER
PLANET GEARS
INTERNAL GEAR POWER INPUT

RA PD 183942

Figure 321. Planetary unit in reduction.


BAND RELEASED
DRUM FREE
CLUTCH APPLIED
ALL GEARS LOCKED AND ROTATE TOGETHER
POWER INPUT
POWER OUTPUT AT SAME SPEED
OIL PRESSURE TO CLUTCH

RA PD 183943

Figure 322. Planetary unit in direct drive.

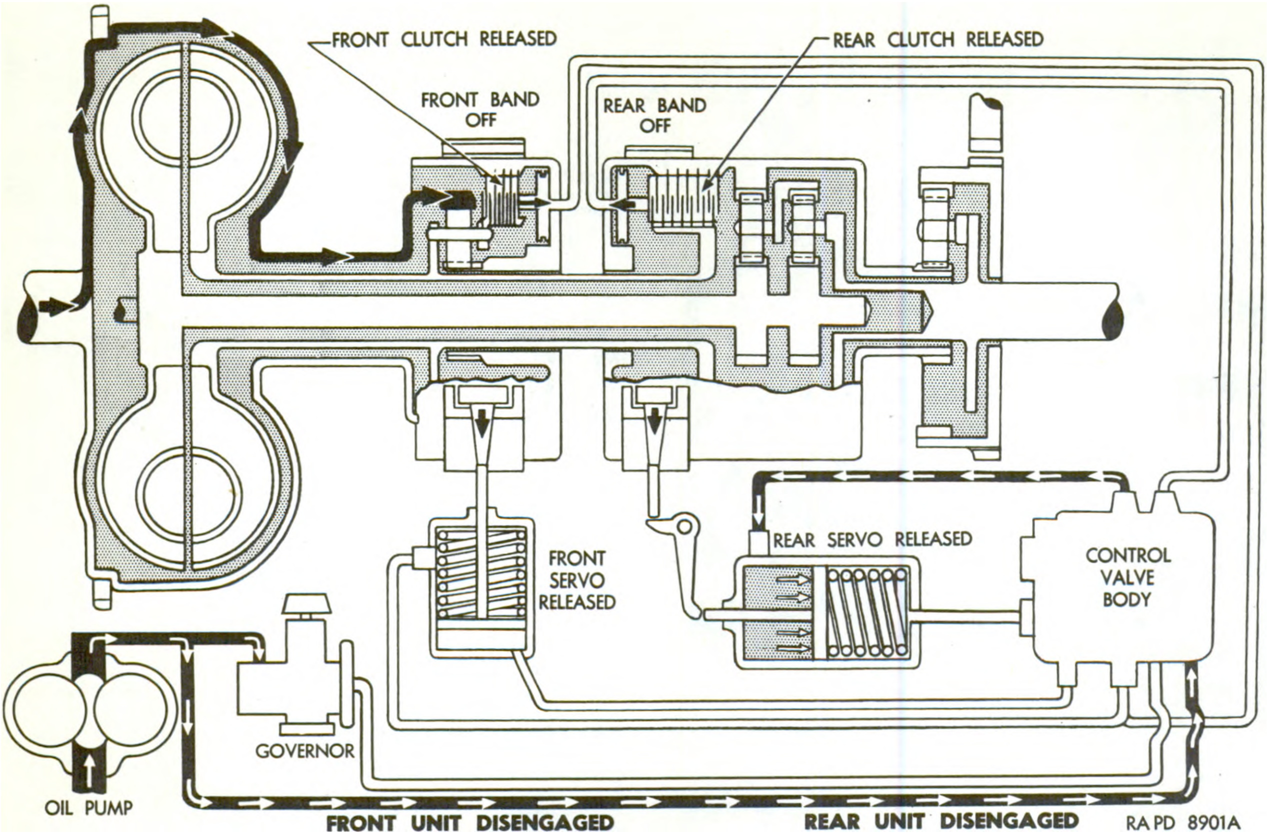


Figure 323. Hydramatic transmission in neutral.

the transmission in neutral and in the four forward transmission speed ranges as well as in reverse. Oil flow is shown by white arrows while power flow is shown by heavy black arrows.

204. Torque Converter Transmission

a. General. Transmissions used in automotive passenger cars with torque converters are generally quite similar, although each may have some special features such as an additional automatically selected high-range gear position or an automatic braking device to prevent car creep when idling in the drive range. The automatic transmissions most widely used with torque converters have planetary gear systems for achieving the low, high, or reverse ranges. A typical transmission of this type is discussed in *b* through *e* below.

b. Construction. Figure 329 is a sectional view of this transmission. The transmission contains a planetary gear system somewhat more complex than that described in paragraph 187 since it contains an additional sun gear (the reverse sun gear) and an extra set of planet pinions. The two sets of planet pinions are known as the planet *short pinions* and the planet *long pinions*. The reverse sun gear and the extra set of planet pinions are included to provide for reversing the transmission. The planetary gear system is controlled by a clutch and a pair of brake bands so as to provide drive, low, reverse, and neutral. Any of these four positions is selected by movement of the selector lever on the steering column. Figure 330 shows the complete planetary gear system, while figures 331, 332, and 333 show the actions in the system during drive, low, and reverse.

c. Drive. In the drive range, the conditions shown in figure 331 are present in the planetary gear system. Operation of the selector lever on the steering column causes the hydraulic valve in the transmission to send oil to the clutch piston so that the clutch is applied. The clutch is a multiple-plate clutch and, when it is applied, it locks the low sun gear to the input shaft through the

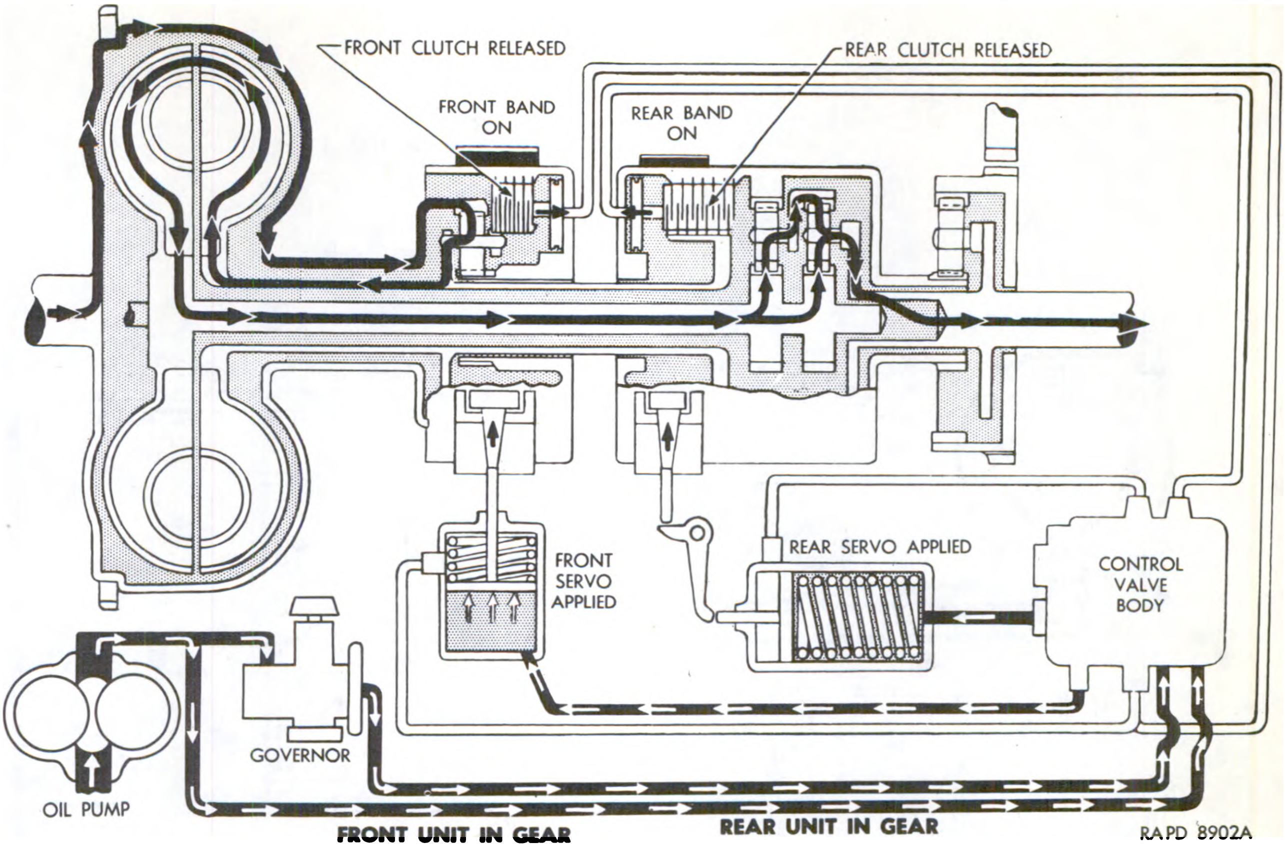


Figure 324. Hydramatic transmission in first speed.

clutch flange. The drive is through the input shaft, clutch hub, clutch plates, clutch flange, low sun gear, and output shaft. The entire assembly turns as a unit to provide a 1 : 1 drive ratio.

d. Low. In the low range, the conditions shown in figure 332 are present in the planetary gear system. Operation of the selector lever on the steering column as it is moved to the low position causes the hydraulic valve in the transmission to open ports that allow oil, under pressure, to flow to the low brake band operating cylinder. This cylinder contains a piston that moves with oil pressure to apply the brake band on the outside diameter of the clutch drum. This holds the drum stationary and this, in turn, holds the clutch flange stationary. Drive is then through the input shaft, to the reverse sun gear, to the long pinions, and to the short pinions which are in mesh with the low sun gear. Since the low sun gear is held stationary with the brake band applied, the short pinions will walk around the low sun gear and as they walk around the sun gear they carry the output shaft, to which they are attached, with them at a reduced speed. The output shaft therefore turns more slowly than the input shaft so that gear reduction is achieved through the transmission.

e. Reverse. In reverse, the output shaft must turn in the opposite direction to the input shaft (fig. 333). This is achieved in the planetary as the selector lever on the steering column is moved to the reverse position. This action operates the hydraulic valve in the transmission so that the reverse brake band is applied. With the band applied to the drum, the reverse internal gear which is part of the drum is held stationary. Drive is then through the input shaft, to the reverse sun gear, to the long pinions, and to the short pinions. Since the short pinions are meshed with the reverse internal gear which is being held stationary, the short pinions will walk around the inside of the internal gear in a reverse direction, rotating the output shaft, to which they are attached, at a reduced speed.

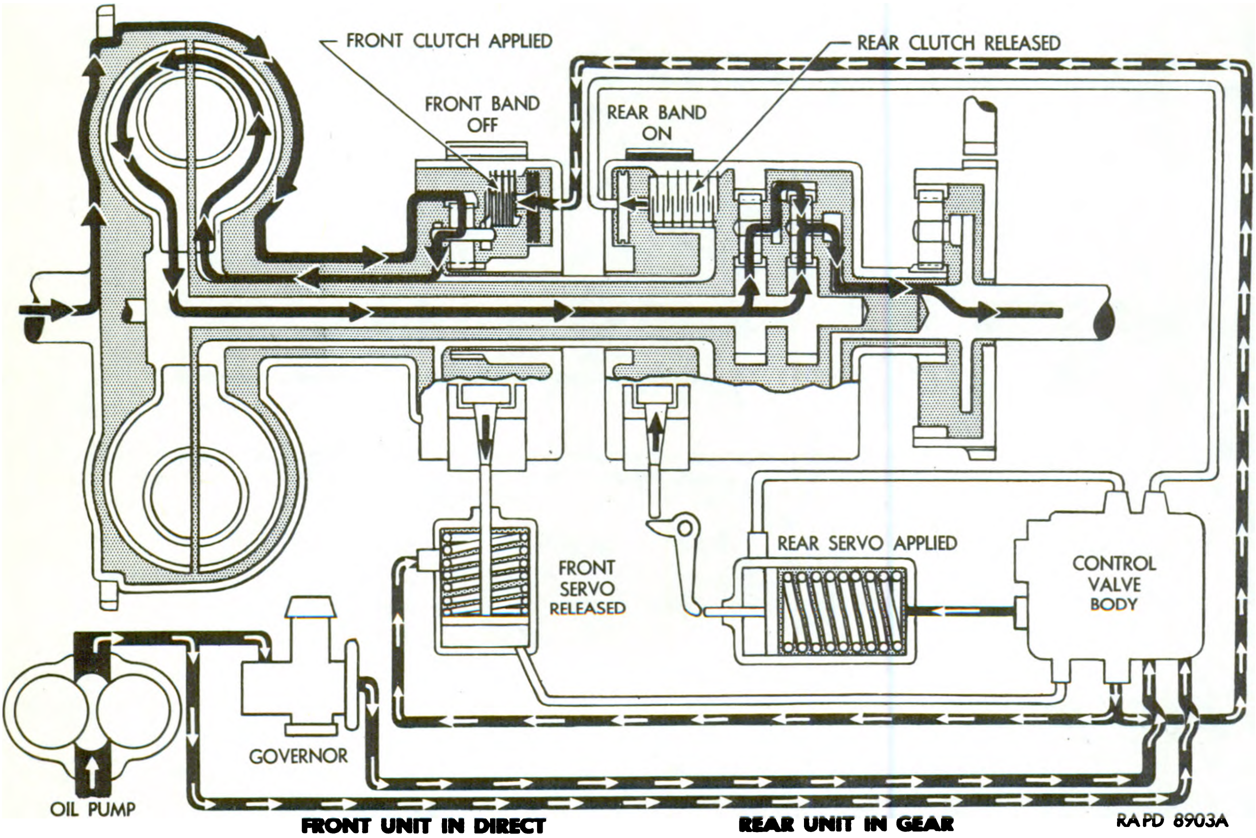

FRONT CLUTCH APPLIED
REAR CLUTCH RELEASED
FRONT BAND
OFF
REAR BAND
ON
REAR SERVO APPLIED
FRONT
SERVO
RELEASED
CONTROL
VALVE
BODY
GOVERNOR
OIL PUMP
FRONT UNIT IN DIRECT
REAR UNIT IN GEAR
RAPD 8903A

Figure 325. Hydramatic transmission in second speed.

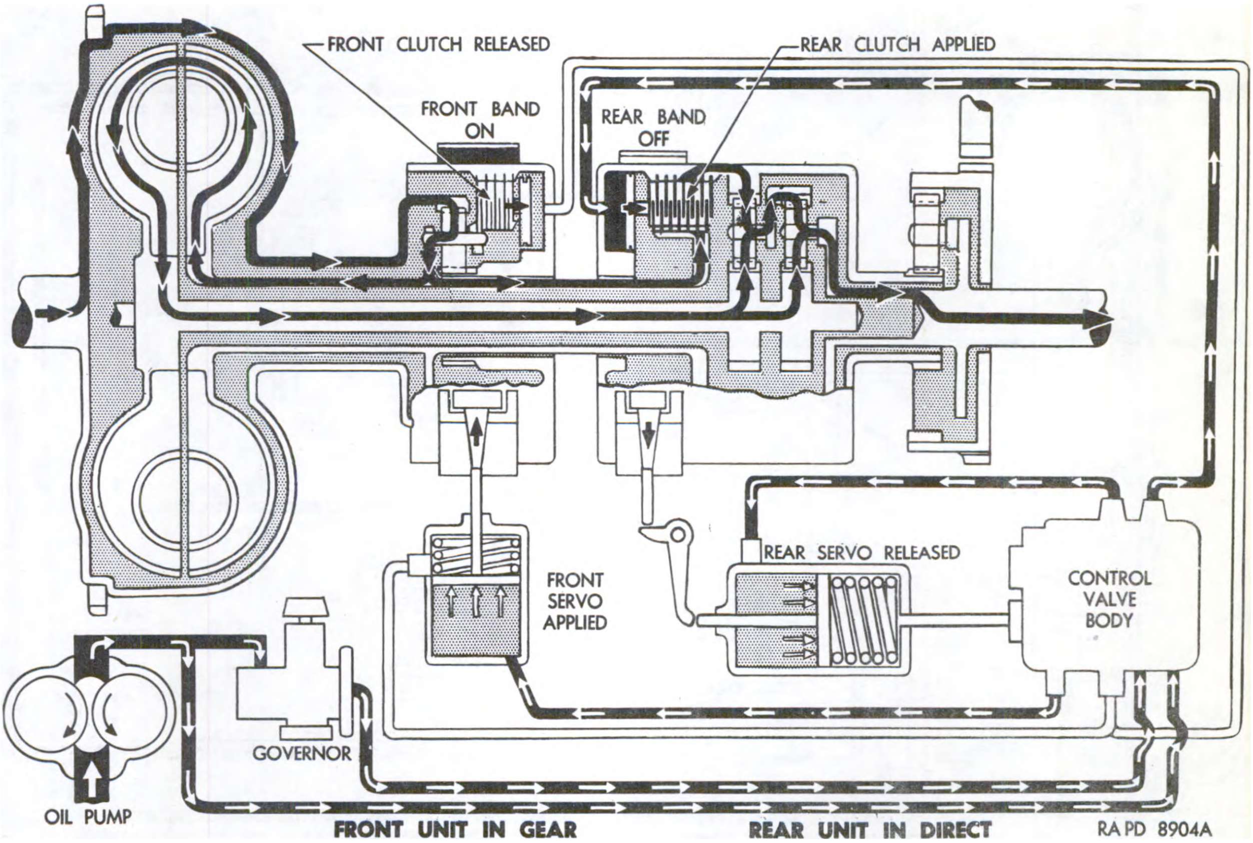

FRONT CLUTCH RELEASED
REAR CLUTCH APPLIED
FRONT BAND ON
REAR BAND OFF
REAR SERVO RELEASED
FRONT SERVO APPLIED
CONTROL VALVE BODY
GOVERNOR
OIL PUMP
FRONT UNIT IN GEAR
REAR UNIT IN DIRECT
RA PD 8904A

Figure 326. Hydramatic transmission in third speed.

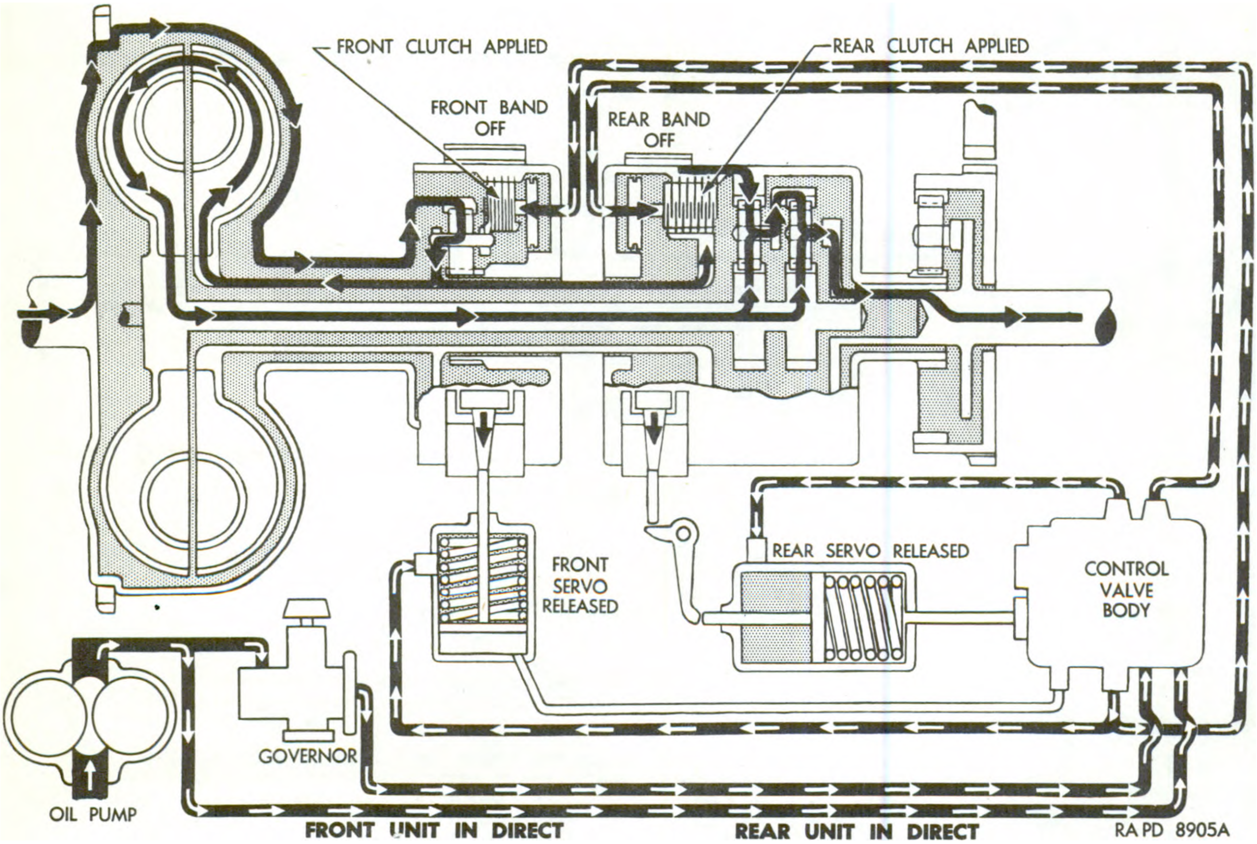

FRONT CLUTCH APPLIED
REAR CLUTCH APPLIED
FRONT BAND OFF
REAR BAND OFF
FRONT SERVO RELEASED
REAR SERVO RELEASED
CONTROL VALVE BODY
GOVERNOR
OIL PUMP
FRONT UNIT IN DIRECT
REAR UNIT IN DIRECT
RA PD 8905A

Figure 327. Hydramatic transmission in fourth speed.

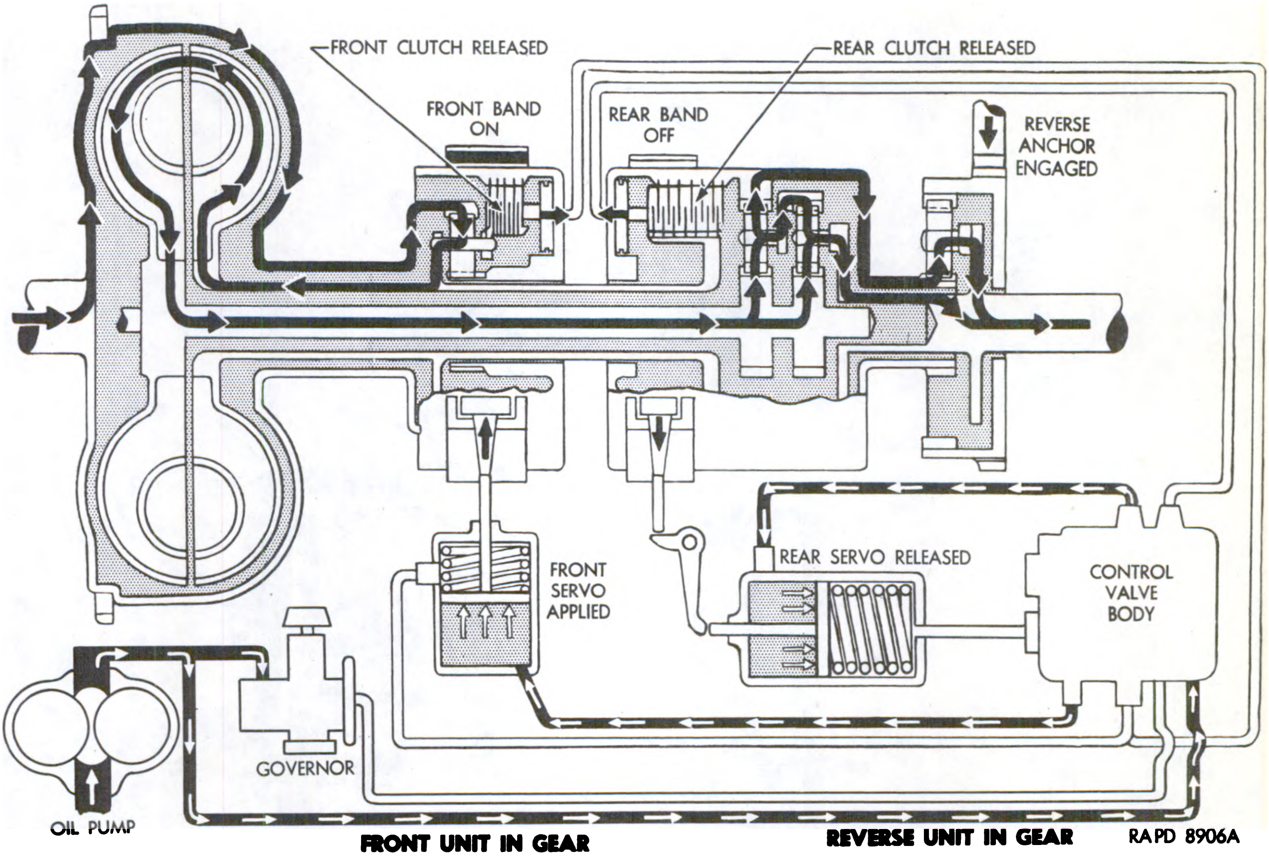
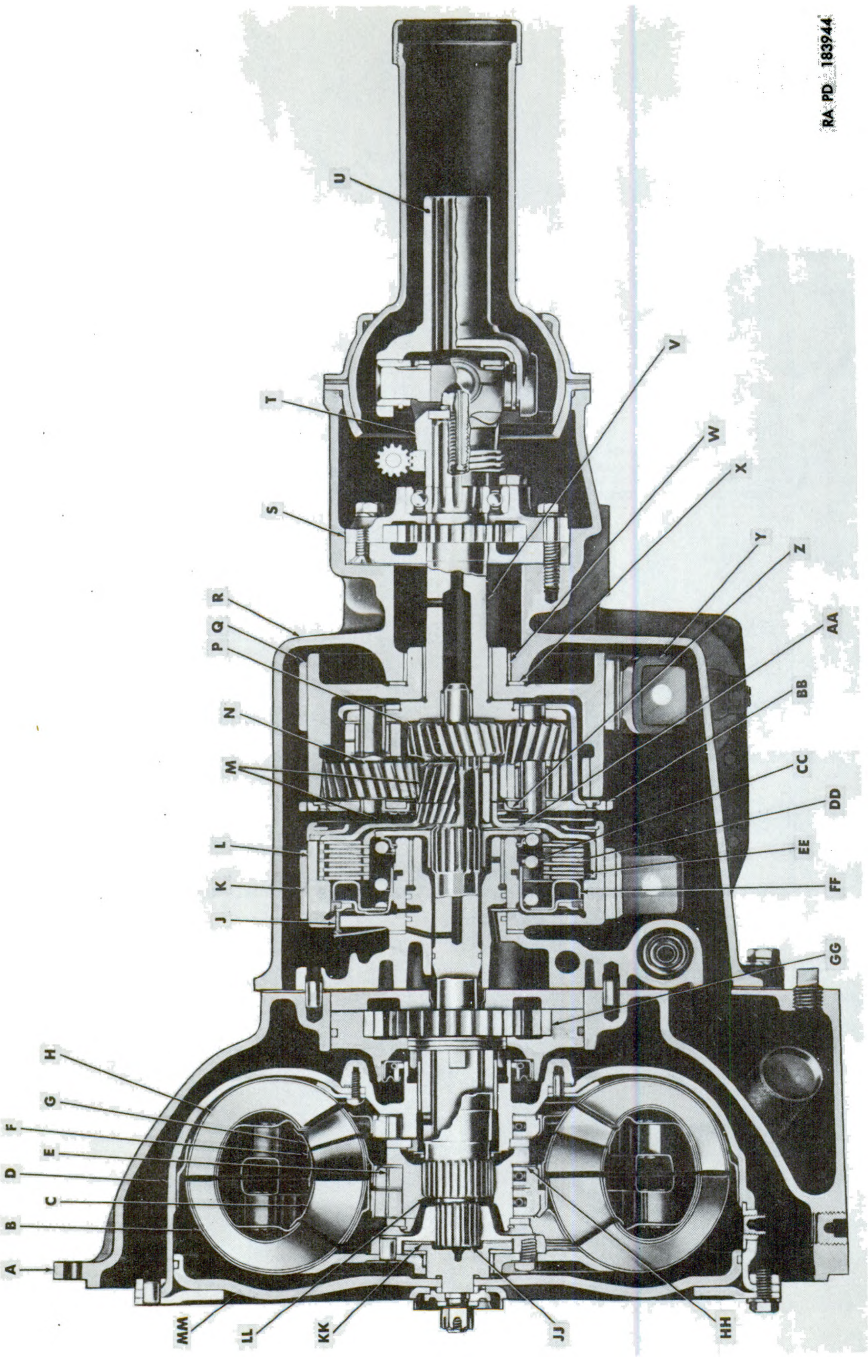
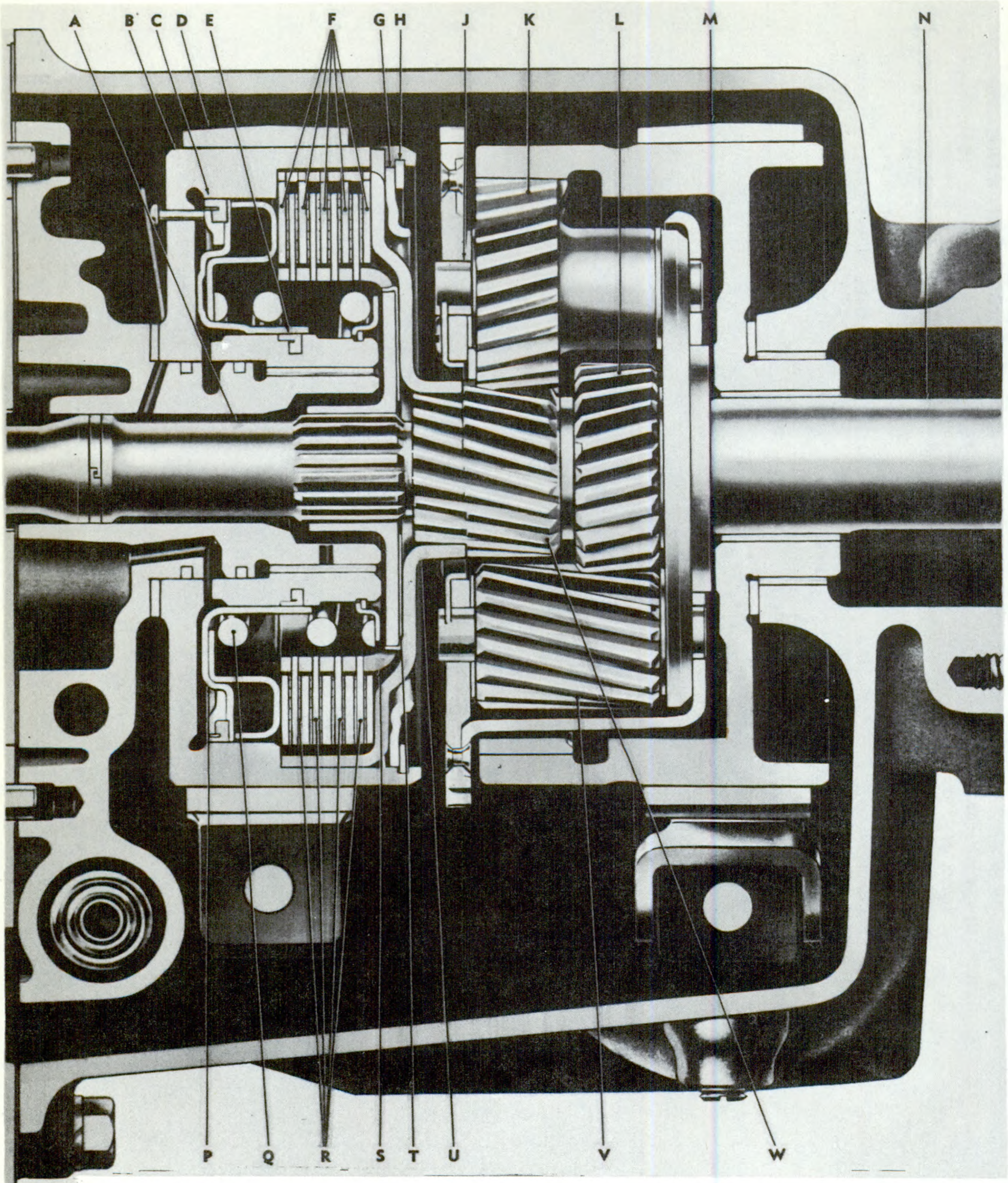

FRONT CLUTCH RELEASED
REAR CLUTCH RELEASED
FRONT BAND ON
REAR BAND OFF
REVERSE ANCHOR ENGAGED
REAR SERVO RELEASED
FRONT SERVO APPLIED
CONTROL VALVE BODY
GOVERNOR
OIL PUMP
FRONT UNIT IN GEAR
REVERSE UNIT IN GEAR
RAPD 8906A

Figure 328. Hydramatic transmission in reverse.


A
B
C
D
E
F
G
H
J
K
L
M
N
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD
EE
FF
GG
HH
JJ
KK
LL
MM
RA PD 183944

A	Transmission housing	L	Clutch drum	U	Universal joint rear yoke	DD	Clutch driven plates
B	Turbine	M	Low sun gear and clutch flange assembly	V	Rear oil pump drive gear	EE	Clutch drive plates
C	Secondary stator	N	Planet short pinion	W	Rear oil pump driven gear	FF	Clutch piston
D	Converter housing	P	Reverse sun gear	X	Planet output shaft	GG	Front oil pump drive gear
E	Overrun cam roller	Q	Reverse brake band	Y	Planet carrier	HH	Stator race
F	Primary stator	R	Transmission case	Z	Planet long pinion	JJ	Input shaft
G	Secondary pump	S	Rear oil pump body	AA	Reverse drum and ring gear	KK	Input shaft drive flange
H	Primary pump	T	Universal joint front yoke	BB	Parking lock gear	LL	Stator support
J	Clutch valve			CC	Clutch spring	MM	Converter cover
K	Low brake band						

Figure 329. Automatic transmission with planetary gear system—sectional view.



A	Input shaft	J	Planet pinion pin	S	Clutch hub
B	Clutch drum	K	Planet short pinion	T	Clutch flange
C	Clutch piston outer ring seal	L	Reverse sun gear	U	Reverse drum and ring gear
D	Low brake band	M	Reverse brake band	V	Planet long pinion
E	Clutch piston inner ring seal	N	Output shaft	W	Low sun gear
F	Clutch driven plates	P	Clutch piston		
G	Clutch flange retainer	Q	Clutch spring		
H	Clutch flange retainer ring	R	Clutch drive plates		

Figure 330. Complete planetary gear system of transmission shown in figure 329.

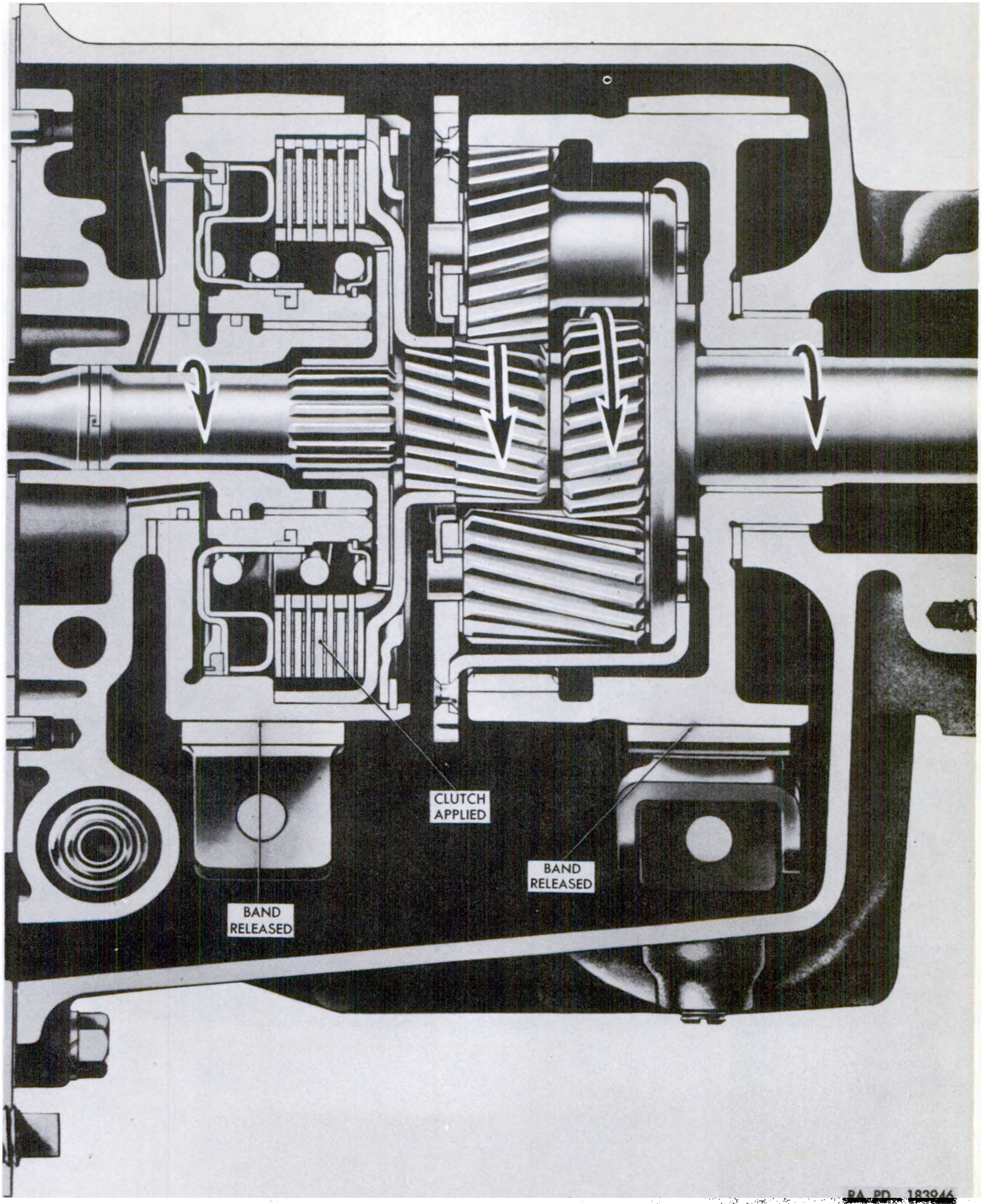

CLUTCH APPLIED
BAND RELEASED
BAND RELEASED
RA PD 183946

Figure 331. Power flow in drive range.

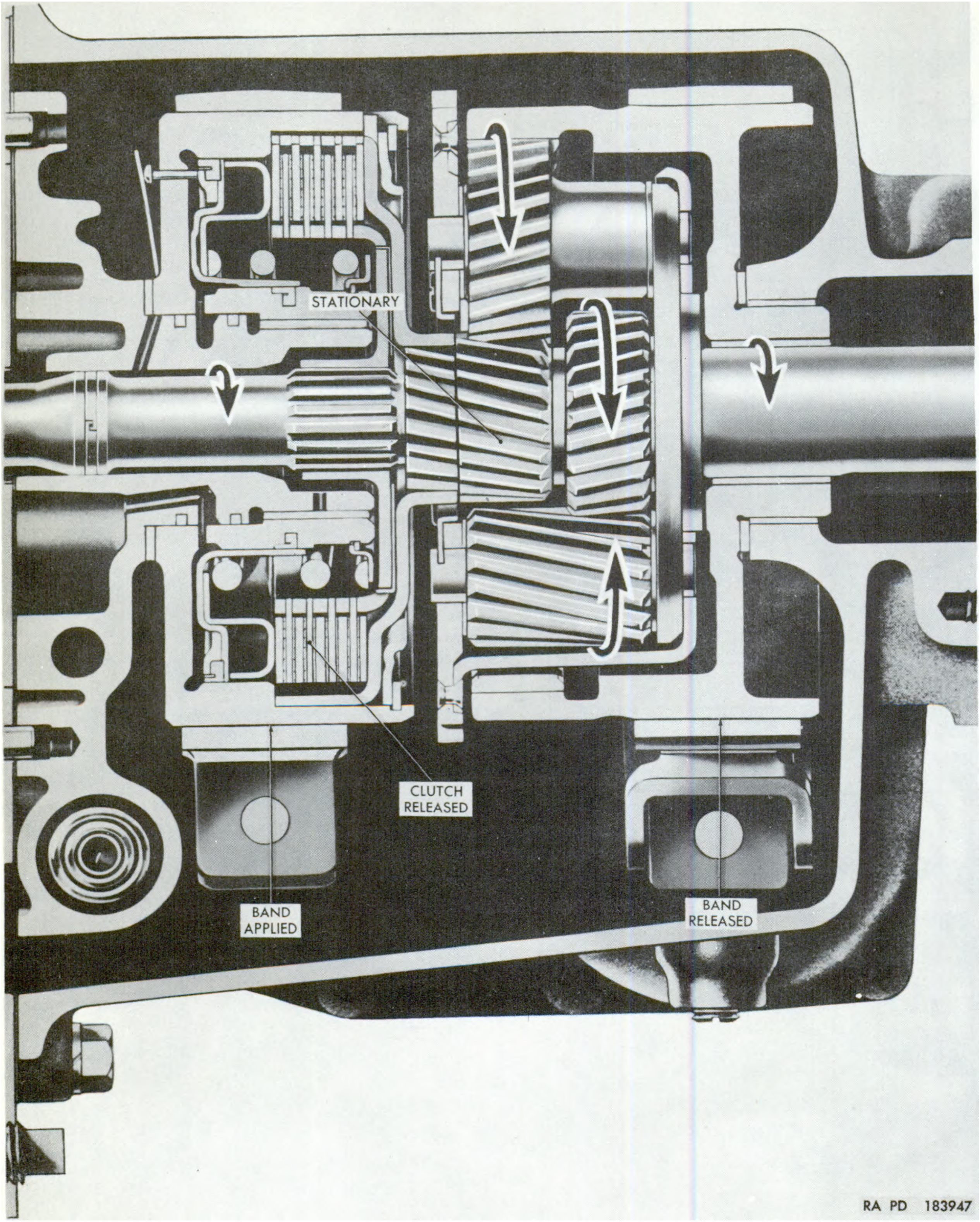

STATIONARY
CLUTCH RELEASED
BAND APPLIED
BAND RELEASED
RA PD 183947

Figure 332. Power flow in low range.

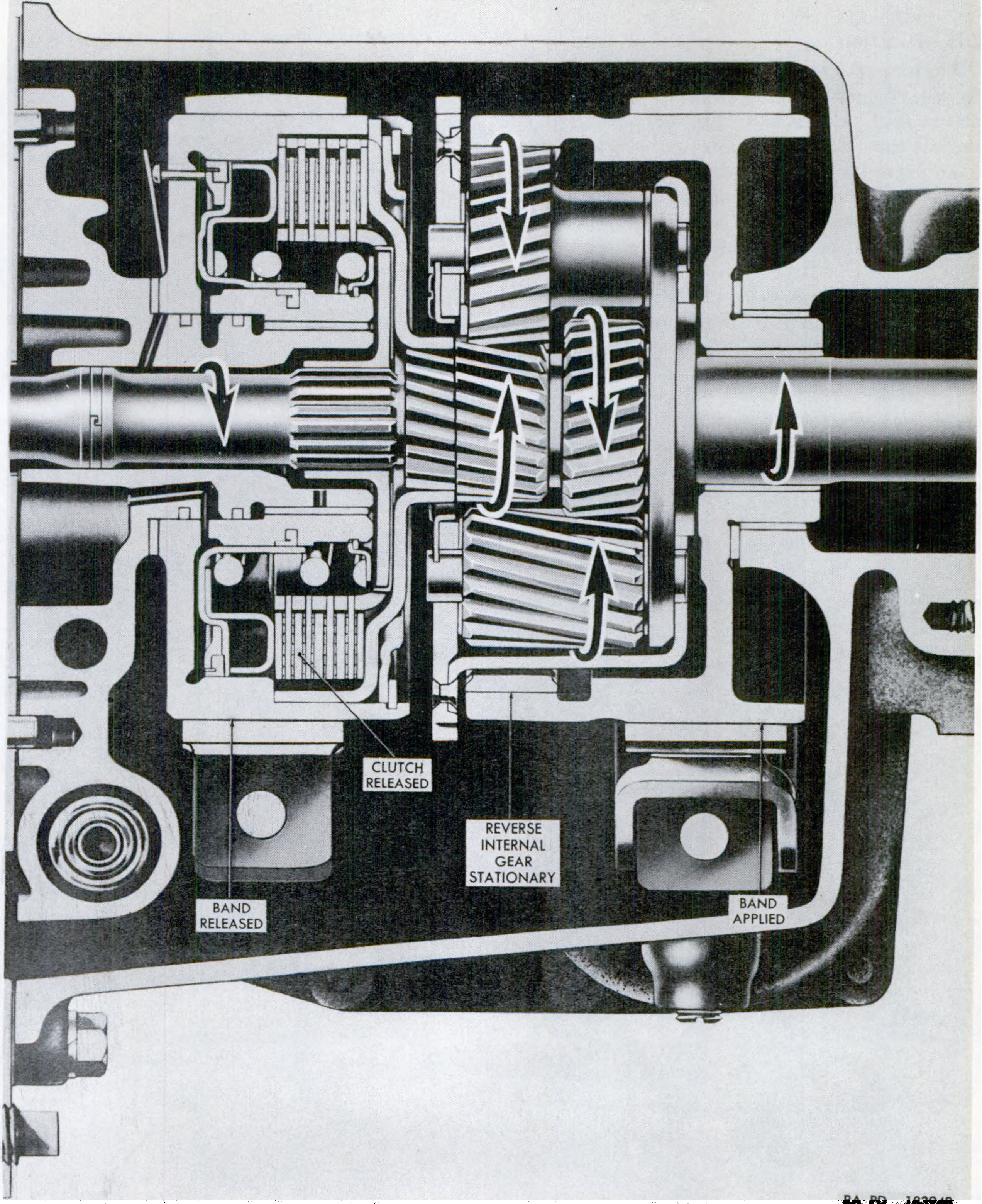

CLUTCH RELEASED
REVERSE INTERNAL GEAR STATIONARY
BAND RELEASED
BAND APPLIED
RA PD 183948

Figure 333. Power flow in reverse.

Section III. TORQMATIC TRANSMISSION

205. Function

The torqmatic transmission is especially adapted for heavy-duty vehicles, allowing easy mobility and rugged performance. Its four speed ranges include three forward and one reverse, and there is an overall torque ratio coverage of 20:1. Inasmuch as all speed ranges consist of frictionally applied planetary drives, each range is immediately obtainable under all driving conditions. Due to the characteristics of the converter, the shift from one range to another can be made, if necessary, with full torque applied, without any substantial change in engine speed or severe shock to the final drive. A manually controlled selector valve engages hydraulically actuated brake bands or friction clutches. The selection of the proper range, which is determined by driving conditions, is the only function necessary for the driver to perform.

206. Construction and Operation

a. Construction.

(1) The torqmatic transmission (figs. 334 and 335) consists basically of two major

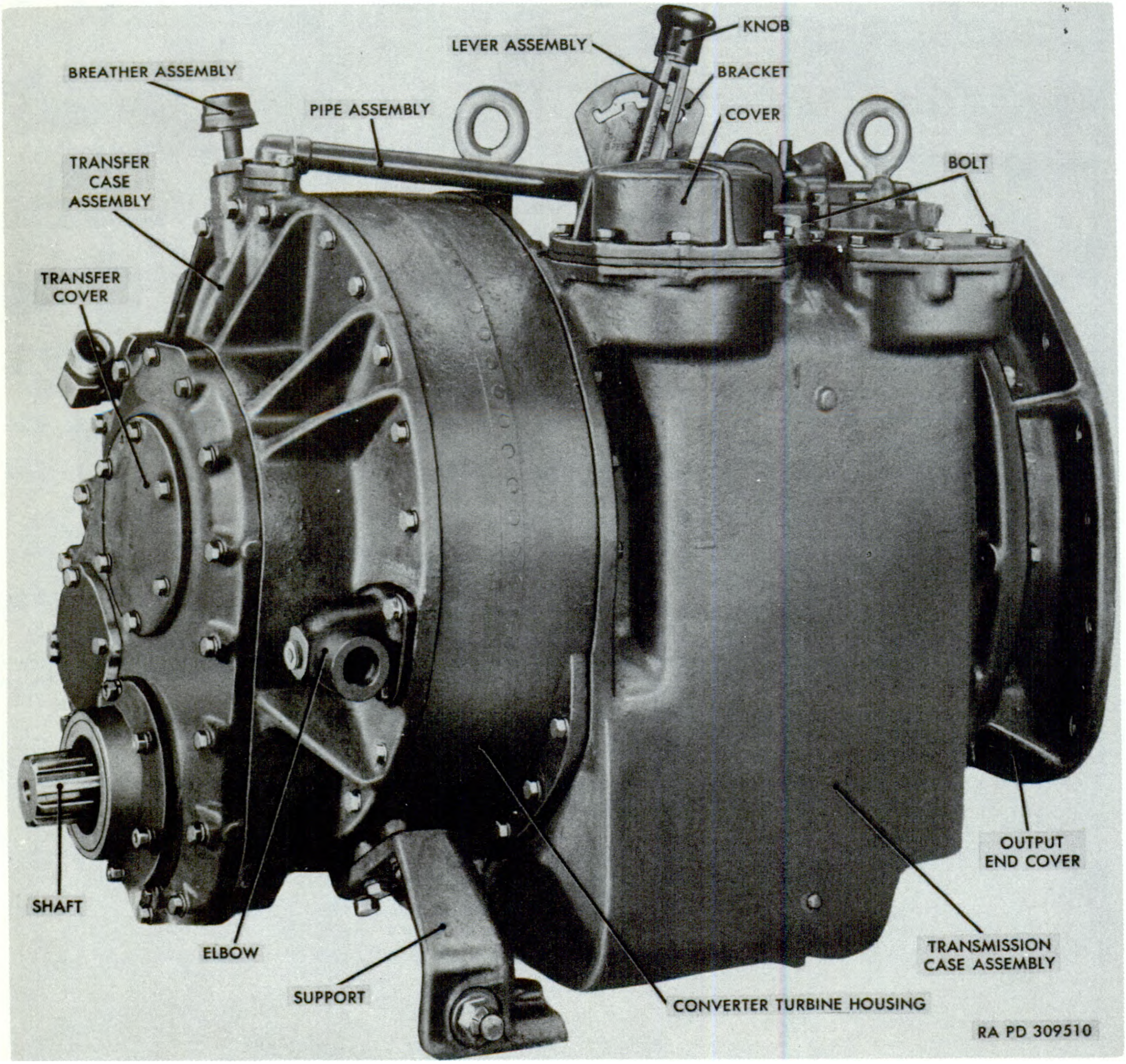

KNOB
LEVER ASSEMBLY
BRACKET
BREATHER ASSEMBLY
PIPE ASSEMBLY
COVER
TRANSFER CASE ASSEMBLY
BOLT
TRANSFER COVER
OUTPUT END COVER
SHAFT
TRANSMISSION CASE ASSEMBLY
ELBOW
SUPPORT
CONVERTER TURBINE HOUSING
RA PD 309510

Figure 334. Torqmatic transmission assembly.

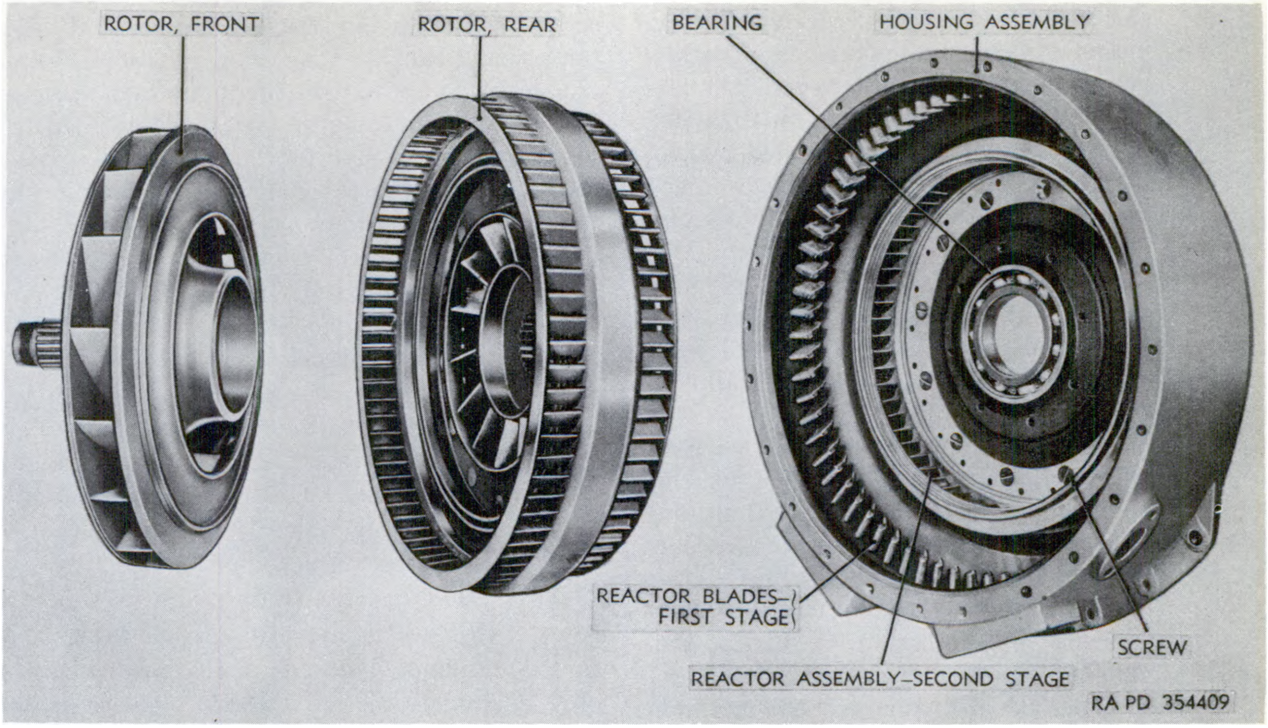


Figure 335. Torqmatic transmission torque converter rotors, housing, and reactor.

units: a hydraulic torque converter combined in series with a 3-speed planetary gear transmission. The construction also includes the transfer assembly. Terms used in describing the positions of the various parts of the transmission are as follows: the *front* end of the transmission is defined as the torque converter, or power input end, which is connected with the engine. The *rear* end is defined as the output end, which is connected through the final drive gear to the driving axle of the vehicle.

(2) The power from the engine enters the transmission by way of the transfer assembly and hydraulic torque converter. The gear train in this case locates the input shaft below the centerline of the transmission in order to obtain a low position for the propeller shaft in the vehicle. This application provides a reduction of 1.20:1 in this transfer assembly, to balance the capacity of the power output of the engine selected. This ratio may be altered to suit the characteristics of various types of engine installations.

(3) The hydraulic torque converter (par. 198) is located between the transfer assembly and the main transmission case. The front pump, which is a hydraulic pressure pump of the internal gear type, is assembled in the transfer unit around the torque converter input shaft.

(4) In back of the converter, the gear train in the transmission consists of two planetary gear sets. The two friction clutches and two brake bands, also located in the transmission case, are alternately engaged to obtain three speeds, thus—

Band and Clutch Application

Position	Brake bands		Clutches	
	Front	Rear	Inner	Outer
Reverse	On	Off	Off	On.
Neutral	Off	Off	On	Off.
Low	Off	Off	On	On.
Intermediate	Off	On	On	Off.
High	On	Off	On	Off.

(5) All gears of the planetary sets are in constant mesh, making it possible under all conditions to shift instantly from one range to another without interrupting the power flow. Individual bands or

clutches are applied hydraulically by means of pistons in the brake application cylinders or annular pistons in the clutch drums. Speed selection is obtained by means of a control lever mounted next to the driver. The control valves are so arranged and coordinated that a practically instaneous shift is obtained from one speed range to the next. This permits shifting either upward or downward under full power; also any possibility of wear and scoring due to overlapping application is eliminated.

(6) A spline on the output shaft in the rear of the transmission is provided for the mounting of the pinion which transmits the power to the final drive gearing. Also driven from this output shaft is the rear oil pump which supplies oil under pressure for actuation of bands and clutches, and for lubrication.

b. Operation. The manual lever is the only control employed by the driver for shifting of the torqmatic transmission. The five positions provided are arranged in the following order: reverse, neutral, low range, intermediate range, and high range. A button latch on the manual lever serves as a detent to prevent shifting more than one step at a time. When ready to start, the lever is shifted to the position required for the anticipated driving conditions and the vehicle is put into motion by stepping on the accelerator.

(1) *Low range.* Low range provides an emergency range for extreme conditions. This range is used when maximum pulling power is needed at speeds below 16 mph.

(2) *Intermediate range.* Intermediate range is used for starting on soft ground and on inclines. This range provides the greatest tractive effort for operation at speeds between 12 and 34 mph.

(3) *High range.* High range is used for driving on good roads or firm, level ground. Under favorable conditions, the vehicle can be started in high range and can be left in this range for all normal driving and on grades up to about 10 percent.

Section IV. CROSS-DRIVE TRANSMISSIONS

207. Function

Several models of cross-drive transmissions are in use, differing in some details from each other. All, however, operate in a similar manner (par. 208). This type of transmission is a combination transmission and steering unit for use on tracked vehicles. It provides hydraulic drive through a torque converter and contains planetary gearing, steering mechanism, braking mechanism, and hydraulically operated clutches. The brakes are foot-operated. The forward- and reverse-speed ranges and the steering are selected and hydraulically controlled from the driver's compartment. The transmission mounts crosswise in the vehicle and drives the two tracks through two flanges, the right output shaft flange and the left output shaft flange (right and left facing toward the front of the vehicle).

208. Construction and Operation

a. General. There are several models of cross-drive transmissions. The CD–500 series is designed for use with engines of 375 to 500 gross horsepower. The CD–850 series is designed for use with engines of 550 to 850 gross horsepower. In the discussion that follows, the CD-500 unit is described in detail. In general, this discussion will apply to all models of cross-drive transmissions. However, reference should be made to the applicable technical manual whenever a detailed study of a particular cross-drive transmission is made. Figure 336 shows an external view of a cross-drive transmission, while figure 337 shows the main subassemblies in the transmission.

b. Torque Converter. The torque converter is a 4-element (or 4-member) converter much like the units described in paragraph 198. Note the location of the converter units in figure 337. The converter contains a pump and turbine plus two stators mounted on the converter ground sleeve by freewheeling clutches. Converter action is shown in figure 338. The pump drives the turbine through the medium of oil as described in paragraph 198. The stators reverse the direction of oil flow into a helping direction as it comes off the turbine vanes. Action is described in (1) through (4) below.

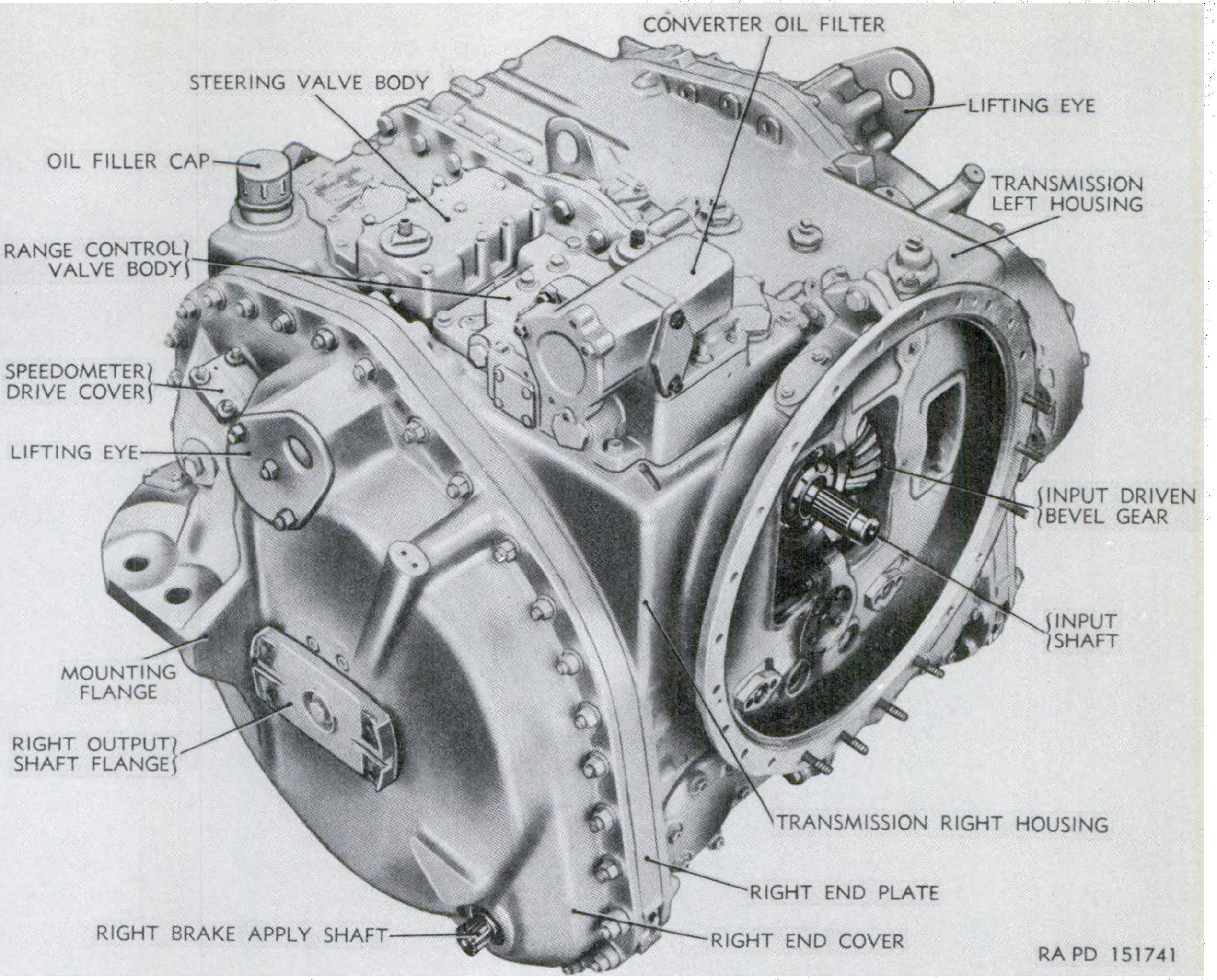

CONVERTER OIL FILTER
STEERING VALVE BODY
LIFTING EYE
OIL FILLER CAP
TRANSMISSION LEFT HOUSING
RANGE CONTROL VALVE BODY
SPEEDOMETER DRIVE COVER
LIFTING EYE
INPUT DRIVEN BEVEL GEAR
INPUT SHAFT
MOUNTING FLANGE
RIGHT OUTPUT SHAFT FLANGE
TRANSMISSION RIGHT HOUSING
RIGHT END PLATE
RIGHT BRAKE APPLY SHAFT
RIGHT END COVER
RA PD 151741

Figure 336. Cross-drive transmission—right-front view.

(1) In the first converter phase, the stators are locked and the oil flow direction is reversed by the action of the two stators. The oil passes from the pump vanes, circulates through the turbine, two stators, and back to the pump.

(2) In the second converter phase, the turbine has picked up speed and there is less torque multiplication. The oil leaves the turbine vanes at less of an angle and it begins to strike the back faces of the first stator vanes. The first stator thus begins to freewheel. In effect, it is simply moving out of the way. The second stator, however, is still needed to change the direction of oil flow.

(3) In the coupling phase, the turbine and pump are revolving at nearly the same speed. The assembly acts like a fluid coupling. Both stators freewheel. Details of torque converter operation are found in paragraph 198.

(4) The converter contains a lock-up clutch which engages automatically when the transmission speed reaches a certain value. As this happens, the pump and turbine are locked together and rotate as a single unit. Power is therefore transmitted mechanically through the converter and no speed reduction or torque multiplication occurs.

c. Planetary Gearing Action in Drive Ranges. The cross-drive transmission contains four planetary gear systems: the low-range planetary, the reverse-range planetary, and the two output planetaries. The low- and reverse-range planetaries are

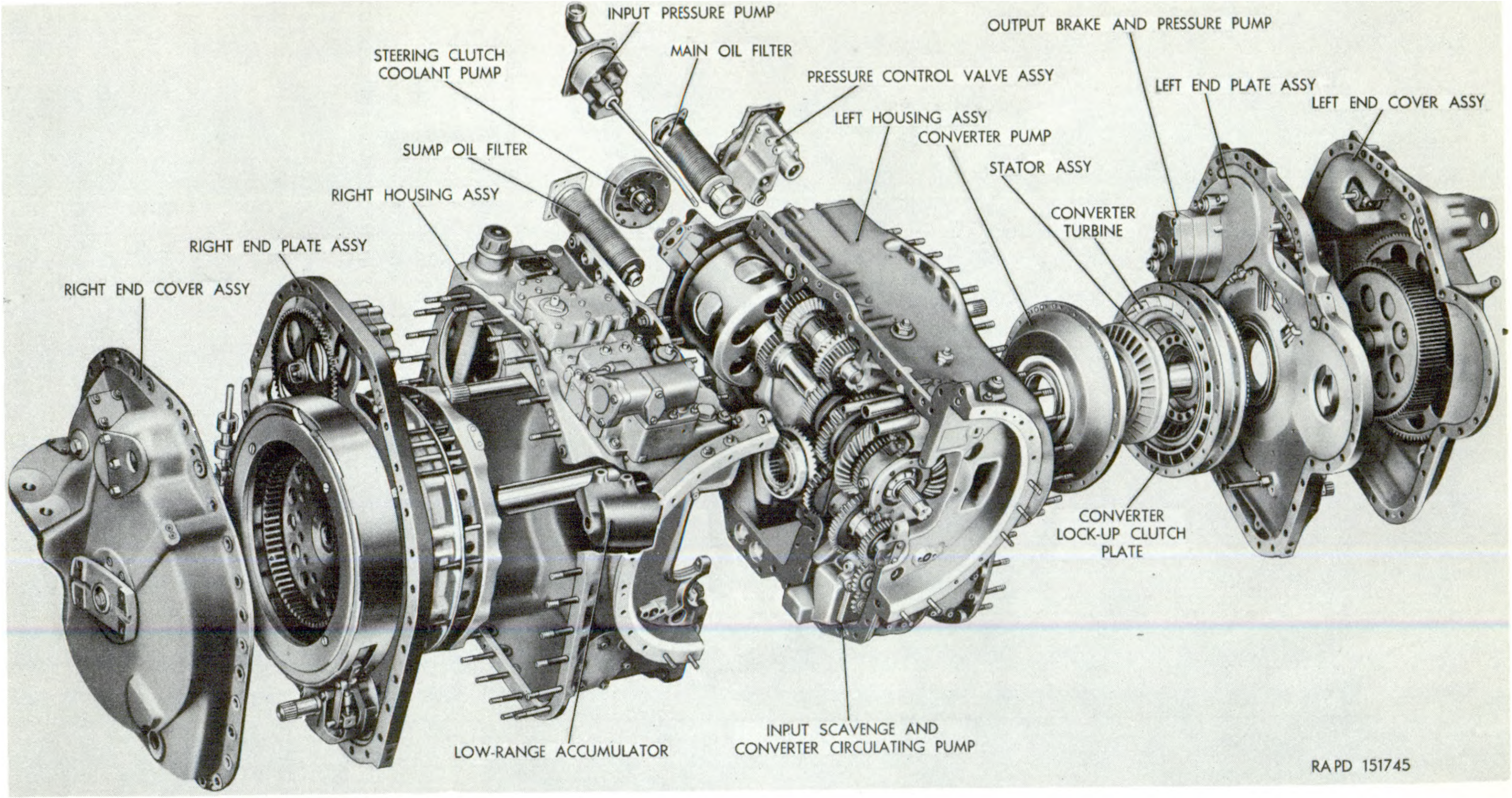

INPUT PRESSURE PUMP
OUTPUT BRAKE AND PRESSURE PUMP
STEERING CLUTCH COOLANT PUMP
MAIN OIL FILTER
PRESSURE CONTROL VALVE ASSY
LEFT END PLATE ASSY
LEFT END COVER ASSY
LEFT HOUSING ASSY
CONVERTER PUMP
SUMP OIL FILTER
STATOR ASSY
RIGHT HOUSING ASSY
CONVERTER TURBINE
RIGHT END PLATE ASSY
RIGHT END COVER ASSY
CONVERTER LOCK-UP CLUTCH PLATE
LOW-RANGE ACCUMULATOR
INPUT SCAVENGE AND CONVERTER CIRCULATING PUMP
RA PD 151745

Figure 337. ***Cross-drive transmission disassembled into main subassemblies.***

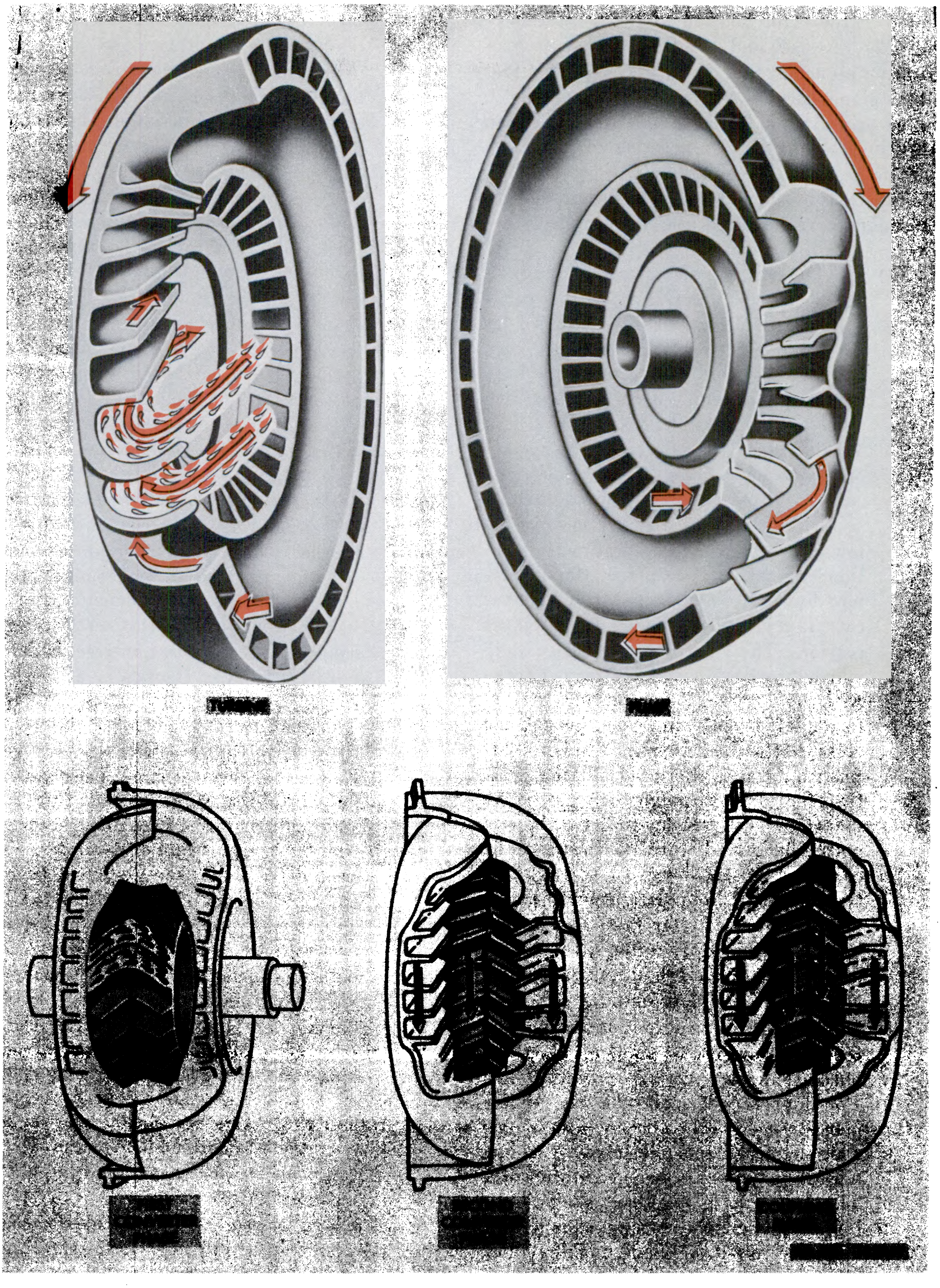

TURBINE
PUMP

Figure 338. Torque converter construction and principles of operation.

located in the right housing of the transmission (fig. 337). At each end of the cross-drive shaft is an output planetary that drives the output flanges. All the planetaries are similar, having four planet pinions and the usual sun gear and internal gear (also called ring gear). Operation of planetary gears is described in detail in paragraph 187*e*. The functions of the planetaries in the cross-drive transmission are described in (1) through (4) below.

(1) The low-range planetary provides an optional gear reduction through the transmission in addition to that provided by the other gearing. The low range may be selected by the driver when extra driving torque is required, as for instance, when pulling through heavy mud or sand. When the driver selects low range by operation of the control valve, oil pressure is directed to the low-range clutch. The clutch engages, thereby locking the low-range ring gear in a stationary position (fig. 339). The planet pinions are now forced to walk around the ring gear, carrying with them the low-range planet carrier. The right output ring gear, to which the planet carrier is attached, turns with the carrier. This rotation is carried to the left output ring gear through the cross shaft, which is splined to both output ring gears. Both output ring gears therefore drive through their respective planetary gear systems to drive the two output flanges. Figure 339 illustrates the complete power flow path through the transmission. Note that the power passes through the converter first, then to the low-range sun gear, through the planet pinions, carrier, right output ring gear, cross-shaft, and left output ring gear, and from the two output ring gears through the output planetaries to the output flanges.

(2) For high-range operation, the driver places the control valve in high range. This action directs oil pressure to the high-range clutch, causing it to engage. This action locks together as a unit the high-range clutch housing, clutch hub, and the cross-drive shaft, making them all rotate at converter-turbine speed. Since the cross-drive shaft is splined to the output ring gears of the two output planetary gear systems, the two output planet carrier assemblies drive the output flanges. Figure 340 shows the power flow through the transmission in high range.

(3) The lockup clutch in the torque converter engages when a predetermined speed is reached in the transmission. Engagement of the lockup clutch locks the converter pump and turbine together so they turn as a unit and no hydraulic torque conversion occurs. Direct mechanical drive is therefore delivered from the transmission input shaft, through the high-range clutch, to the transmission output. The power path is the same as shown in figure 340, the only difference being that no speed reduction or torque increase occurs in the torque converter.

(4) When the driver places the range control valve in reverse, oil pressure is directed to the reverse-range clutch, causing it to engage. The reverse-range clutch hub and reverse-range planet carrier are held stationary. This causes the reverse-range planet pinions to rotate in the direction shown in figure 341 as they are driven by the reverse-range sun gear. The reverse-range planet pinions, in turn, drive the reverse-range ring gear. Since the reverse-range ring gear is bolted to the right output ring gear (through the low-range planet carrier), the right output ring gear rotates. The cross-drive shaft, being splined to both the right output ring gear and the left output ring gear, carries the rotary motion to the left output ring gear so that both ring gears drive through their respective output planetary systems to drive the two output flanges. Note that the direction of rotation is reversed as compared to the two forward driving ranges (low and high) shown in figures 339 and 340. This reversal results because the reverse-range clutch holds the reverse-range planet carrier stationary as shown in figure 341.

d. Steering. Steering is accomplished through the two steer clutches, the steer differential, and the gearing to the output planetary sun gears. Driving power is carried to the two steer clutches

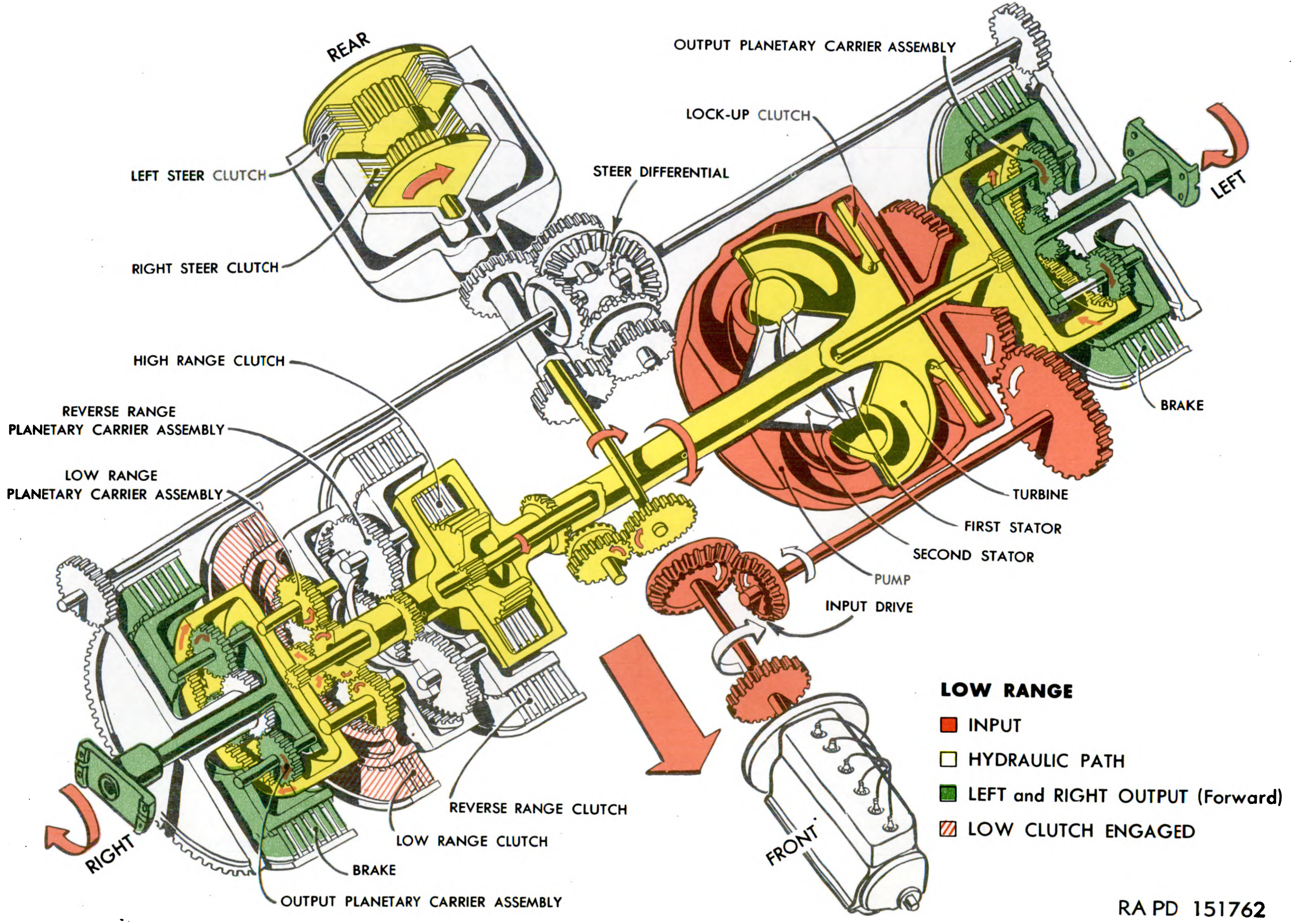

REAR
OUTPUT PLANETARY CARRIER ASSEMBLY
LOCK-UP CLUTCH
LEFT
LEFT STEER CLUTCH
STEER DIFFERENTIAL
RIGHT STEER CLUTCH
HIGH RANGE CLUTCH
BRAKE
REVERSE RANGE PLANETARY CARRIER ASSEMBLY
LOW RANGE PLANETARY CARRIER ASSEMBLY
TURBINE
FIRST STATOR
SECOND STATOR
PUMP
INPUT DRIVE
LOW RANGE
🟥 INPUT
☐ HYDRAULIC PATH
🟩 LEFT and RIGHT OUTPUT (Forward)
▨ LOW CLUTCH ENGAGED
REVERSE RANGE CLUTCH
LOW RANGE CLUTCH
RIGHT
BRAKE
FRONT
OUTPUT PLANETARY CARRIER ASSEMBLY
RA PD 151762

Figure 339. Power flow through cross-drive transmission in low range.

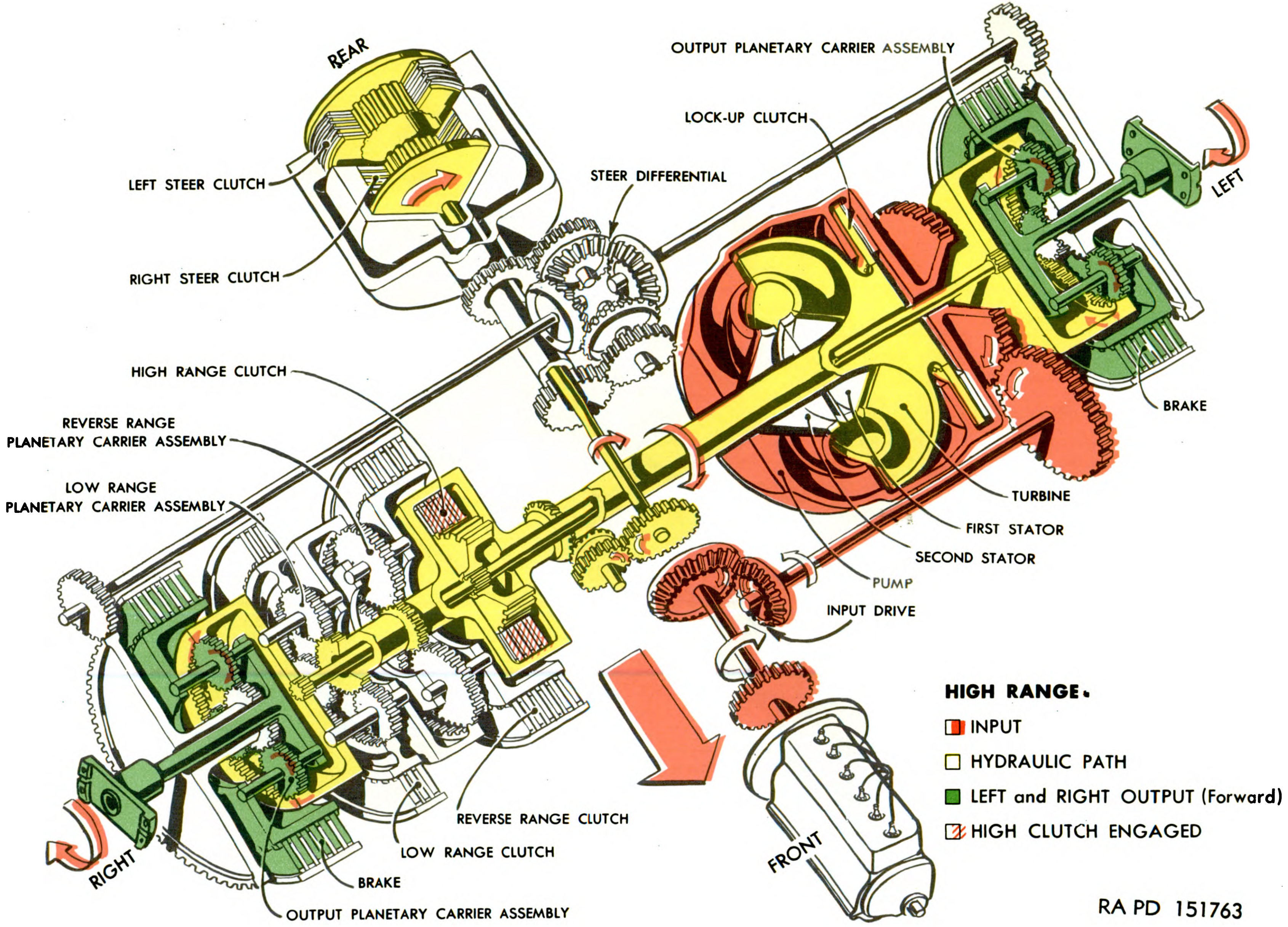

REAR
LEFT STEER CLUTCH
RIGHT STEER CLUTCH
STEER DIFFERENTIAL
LOCK-UP CLUTCH
OUTPUT PLANETARY CARRIER ASSEMBLY
LEFT
BRAKE
HIGH RANGE CLUTCH
REVERSE RANGE
PLANETARY CARRIER ASSEMBLY
LOW RANGE
PLANETARY CARRIER ASSEMBLY
TURBINE
FIRST STATOR
SECOND STATOR
PUMP
INPUT DRIVE
HIGH RANGE.
INPUT
HYDRAULIC PATH
LEFT and RIGHT OUTPUT (Forward)
HIGH CLUTCH ENGAGED
REVERSE RANGE CLUTCH
LOW RANGE CLUTCH
BRAKE
OUTPUT PLANETARY CARRIER ASSEMBLY
RIGHT
FRONT
RA PD 151763

Figure 340. Power flow through cross-drive transmission in high range.

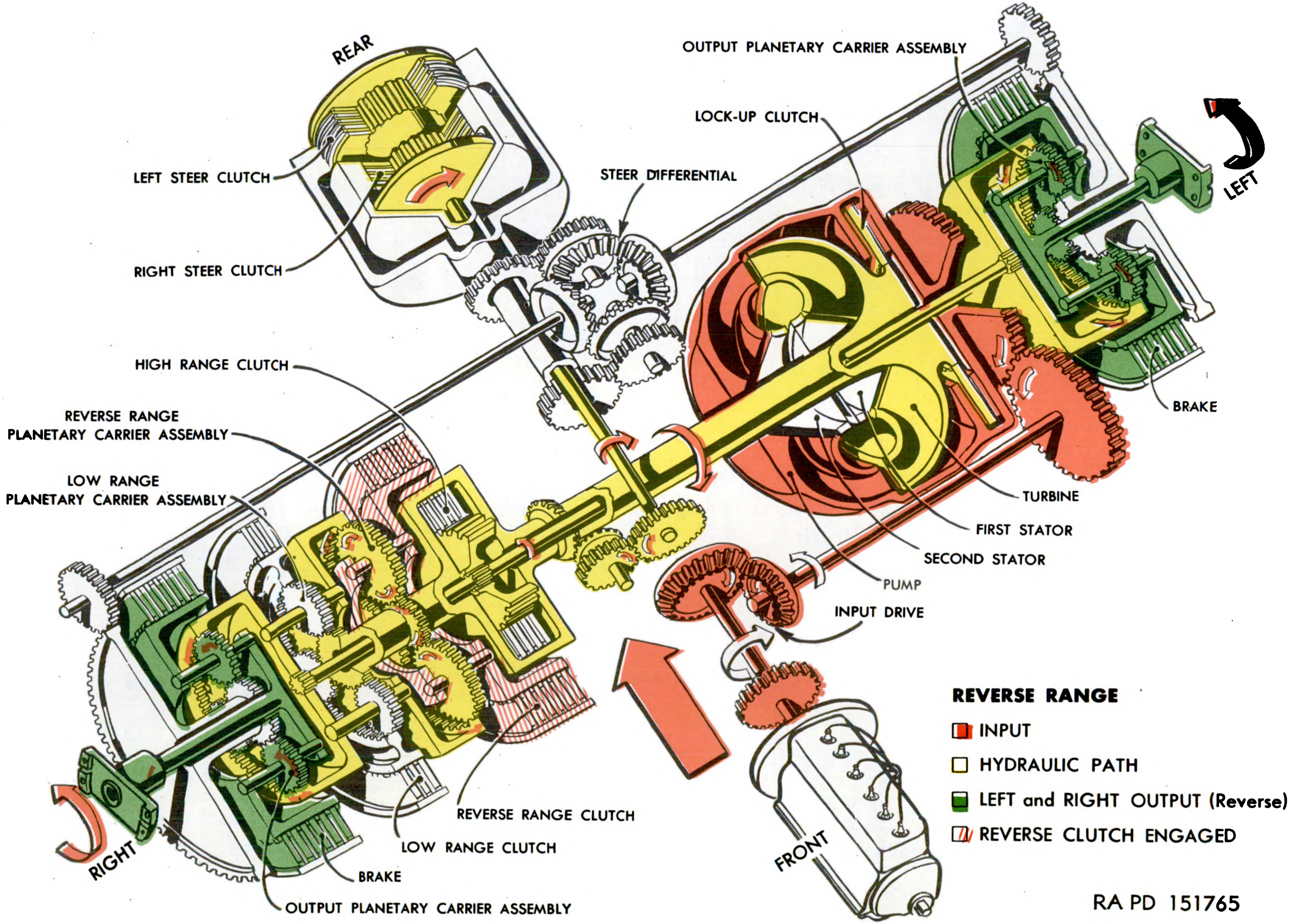

REAR
LEFT STEER CLUTCH
RIGHT STEER CLUTCH
STEER DIFFERENTIAL
LOCK-UP CLUTCH
OUTPUT PLANETARY CARRIER ASSEMBLY
LEFT
BRAKE
HIGH RANGE CLUTCH
REVERSE RANGE PLANETARY CARRIER ASSEMBLY
LOW RANGE PLANETARY CARRIER ASSEMBLY
TURBINE
FIRST STATOR
SECOND STATOR
PUMP
INPUT DRIVE
REVERSE RANGE
🟥 INPUT
☐ HYDRAULIC PATH
🟩 LEFT and RIGHT OUTPUT (Reverse)
▨ REVERSE CLUTCH ENGAGED
RIGHT
REVERSE RANGE CLUTCH
LOW RANGE CLUTCH
BRAKE
OUTPUT PLANETARY CARRIER ASSEMBLY
FRONT
RA PD 151765

Figure 341. Power flow through cross-drive transmission in reverse gear.

at all times by the gearing on the converter turbine output shaft. However, when neither of the steer clutches is engaged and the vehicle is moving straight ahead or straight reverse (both output flanges turning at the same speed and in same direction), no power is passing through the steering system. But when one of the steer clutches is engaged, power is carried through the steering system, and this causes the two sun gears in the two output planetaries to turn in opposite directions. As they turn in opposite directions, they impart opposing rotary motion to the output planetaries as explained in (1) through (6) below.

(1) *Left steer in neutral range.* Steering can be accomplished with the transmission in neutral; that is, with no power passing through the cross-drive shaft to the output planetaries. With this condition, the low-, high-, and reverse-range clutches are disengaged. No driving power is being transmitted to the output ring gears. When the left steering valve is actuated by the driver for left steer, oil pressure is introduced into the left-steer-clutch piston, causing the left-steer clutch to engage as indicated in figure 342. The clutch receives pressure proportional to the amount of steer applied, so that any variation from light to hard left steering will result. With the left-steer clutch engaged, the drive is from the turbine output shaft, through the left-steer clutch to the rear differential bevel gear. This bevel gear then drives the two engaged bevel gears in opposite directions, as shown in figure 342. These driven bevel gears therefore drive the two output sun gears in opposite directions. The output ring gears cannot turn in opposite directions since they are both splined to the cross-drive shaft. The output ring gears remain stationary and the two sun gears cause the planet pinions to rotate and walk around the ring gears, thereby rotating the planet carriers. The right planet carrier rotates in a forward direction and the left planet carrier rotates in the reverse direction, as shown. This causes the right output flange to rotate in a forward direction and the left output flange to rotate in the reverse direction. Under the conditions described, which produce left steering, the vehicle pivots to the left.

(2) *Right steer in neutral range.* For right steer in neutral range, the low-, high-, and reverse-range clutches are disengaged and no driving power is being transmitted to the output ring gears. These are the same conditions as when a left steer in neutral range is being made. When the right steering valve is actuated by the driver for right steer, oil pressure is introduced into the right-steer-clutch piston, thereby causing the right-steer clutch to engage as indicated in figure 343. As with left steering, the clutch receives pressure proportional to the amount of steering applied so that any variation from light to hard right steering will result. With the right-steer clutch engaged, the drive is from the turbine output shaft, through the right-steer clutch to the differential front bevel gear. This bevel gear then drives the two engaged bevel gears in opposite directions as shown in figure 343. Notice that these two bevel gears are turning in directions that are the reverse of those shown in figure 342. The two bevel gears drive the two output sun gears in opposite directions as shown, causing the right output flange to rotate in a reverse direction and the left output flange to rotate in a forward direction so that the vehicle pivots to the right.

(3) *Left steer in low range.* In low range, the output ring gears are driving the output planet carriers forward so that both output flanges are rotating in a forward direction. When the left steering valve is actuated by the driver for left steering, oil pressure is directed to the left-steer-clutch piston, engaging the left-steer clutch (fig. 344). The clutch receives pressure proportional to the amount of steer applied. When the left-steer clutch engages, driving power is applied to the rear differential bevel gear. This bevel gear then drives the two engaged bevel gears in opposite directions exactly as in left steer in neutral range (fig. 342). This gives a forward rotation to the right

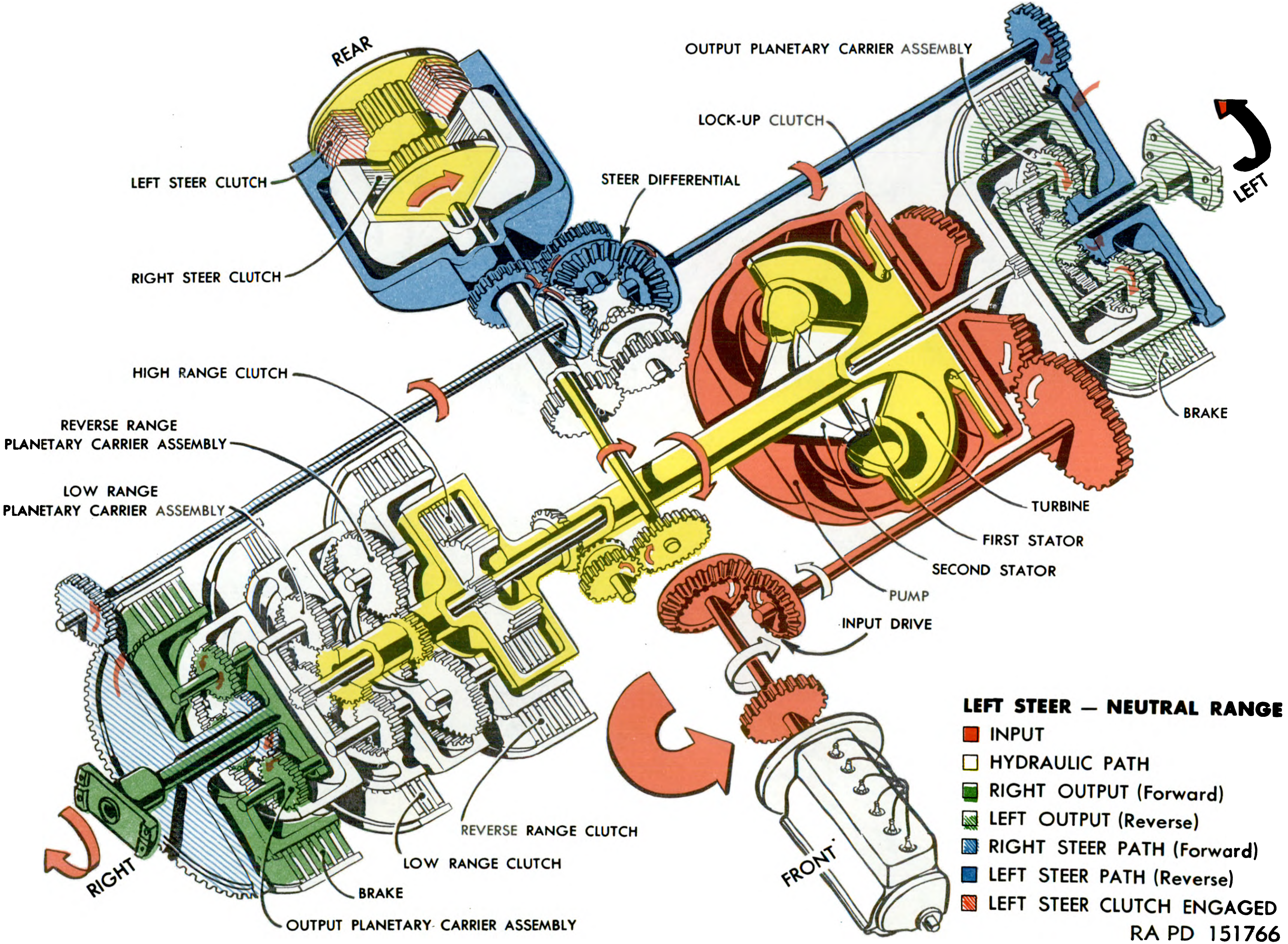

REAR
LEFT STEER CLUTCH
RIGHT STEER CLUTCH
STEER DIFFERENTIAL
OUTPUT PLANETARY CARRIER ASSEMBLY
LOCK-UP CLUTCH
LEFT
BRAKE
HIGH RANGE CLUTCH
REVERSE RANGE PLANETARY CARRIER ASSEMBLY
LOW RANGE PLANETARY CARRIER ASSEMBLY
TURBINE
FIRST STATOR
SECOND STATOR
PUMP
INPUT DRIVE
FRONT
RIGHT
REVERSE RANGE CLUTCH
LOW RANGE CLUTCH
BRAKE
OUTPUT PLANETARY CARRIER ASSEMBLY
LEFT STEER — NEUTRAL RANGE
🟥 INPUT
☐ HYDRAULIC PATH
🟩 RIGHT OUTPUT (Forward)
▨ LEFT OUTPUT (Reverse)
▨ RIGHT STEER PATH (Forward)
🟦 LEFT STEER PATH (Reverse)
▨ LEFT STEER CLUTCH ENGAGED
RA PD 151766

Figure 342. Power flow in cross-drive transmission during left steering in neutr al range.

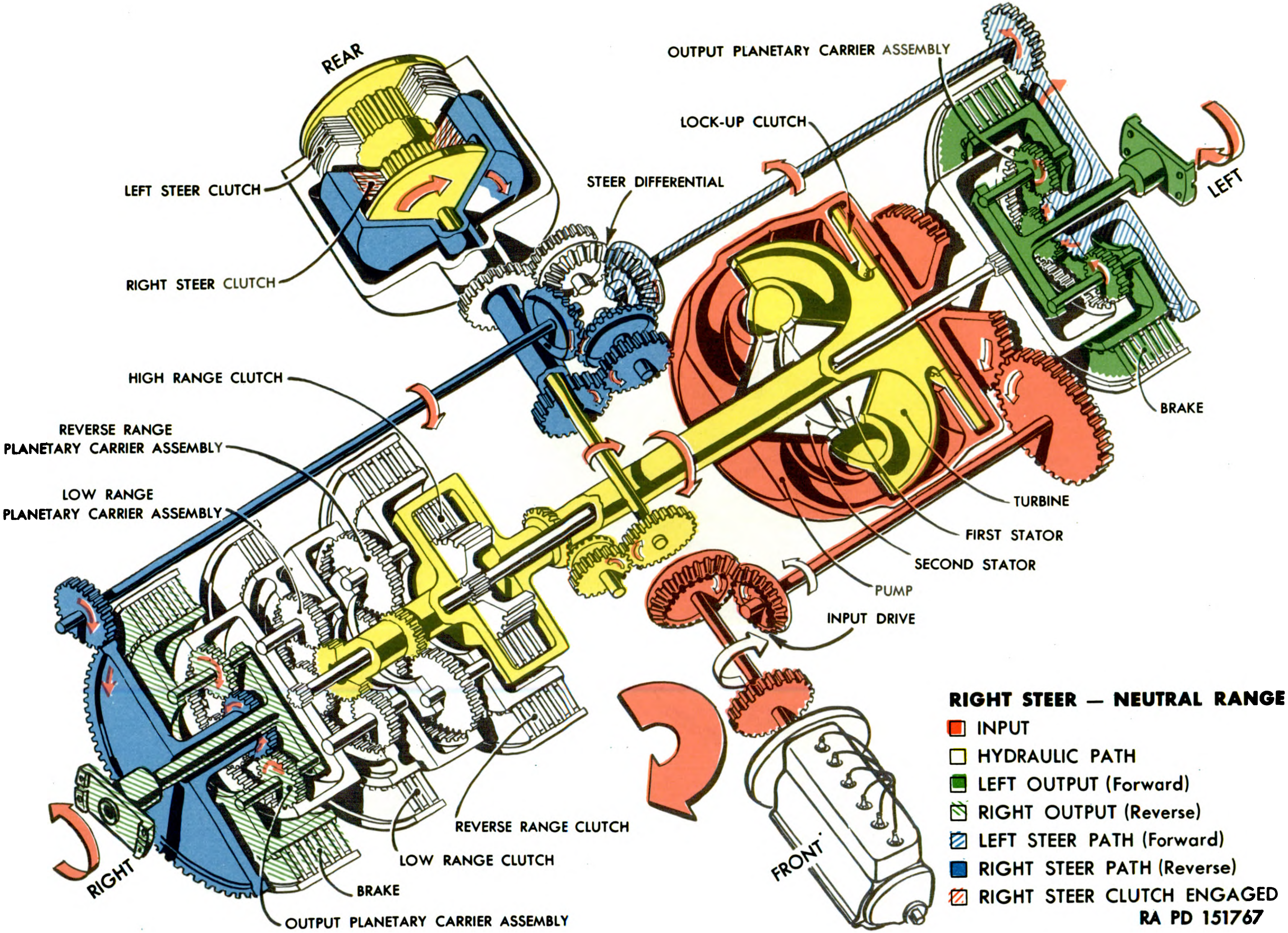

REAR
LEFT STEER CLUTCH
RIGHT STEER CLUTCH
HIGH RANGE CLUTCH
REVERSE RANGE PLANETARY CARRIER ASSEMBLY
LOW RANGE PLANETARY CARRIER ASSEMBLY
RIGHT
BRAKE
OUTPUT PLANETARY CARRIER ASSEMBLY
LOW RANGE CLUTCH
REVERSE RANGE CLUTCH
FRONT
INPUT DRIVE
PUMP
SECOND STATOR
FIRST STATOR
TURBINE
BRAKE
LEFT
OUTPUT PLANETARY CARRIER ASSEMBLY
LOCK-UP CLUTCH
STEER DIFFERENTIAL
RIGHT STEER — NEUTRAL RANGE
🟥 INPUT
☐ HYDRAULIC PATH
🟩 LEFT OUTPUT (Forward)
▨ RIGHT OUTPUT (Reverse)
▨ LEFT STEER PATH (Forward)
🟦 RIGHT STEER PATH (Reverse)
▨ RIGHT STEER CLUTCH ENGAGED
RA PD 151767

Figure 343. Power flow in cross-drive transmission during right steering in neutral range.

output sun gear and a reverse rotation to the left output sun gear. Since both output ring gears are rotating forward, the forward rotation of the right output sun gear will increase the rotary speed of the right output planet carrier and the right output flange. At the same time, the reverse rotation of the left output sun gear will reduce the rotary speed of the left output planet carrier and the left output flange. With the right output speeded up and the left output slowed down, the vehicle steers to the left.

(4) *Right steer in low range.* Right steer in low range is very similar to left steer in low range, described in (3) above. The only difference is that, in right steer, the right-steer clutch is engaged (fig. 343), so that the differential front bevel gear drives the two engaged bevel gears. This gives the right output sun gear a reverse rotation and the left output sun gear a forward rotation. Since both output ring gears are rotating forward, the forward rotation of the left output sun gear will increase the rotary speed of the left output planet carrier and the left output flange. At the same time, the reverse rotation of the right output sun gear will reduce the rotary speed of the right output planet carrier and the right output flange. With the right output slowed down and the left output speeded up, the vehicle steers to the right.

(5) *Right and left steer in high range.* Right steer and left steer in high range are identical to right steer and left steer in low range, described in (3) and (4) above, except that the transmission is in high range (fig. 340).

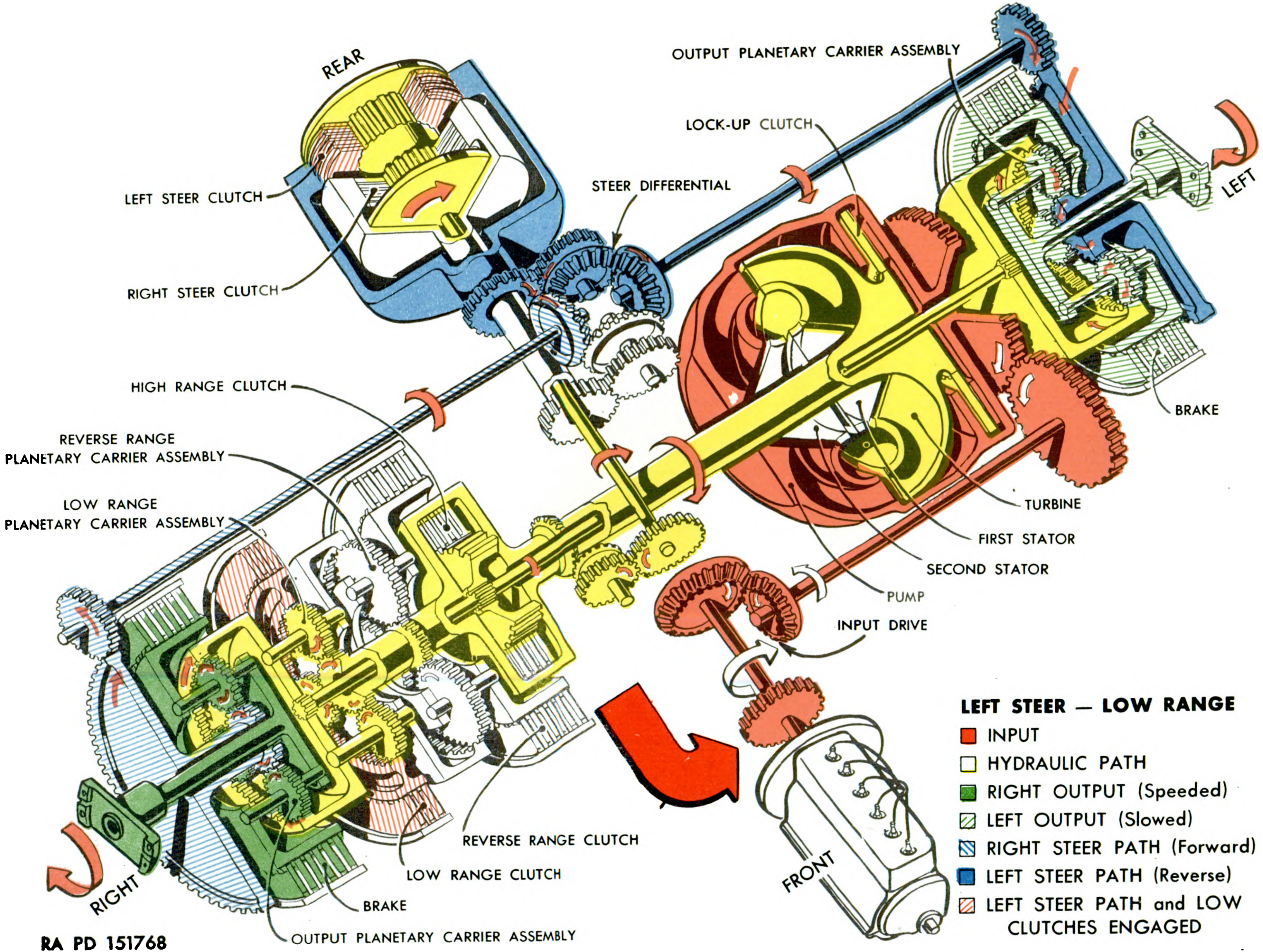
(6) *Right and left steer in reverse range.* Right steer and left steer in reverse range are identical to right steer and left steer in low range or in high range, described in (3), (4), and (5) above, except that the transmission is in reverse range (fig. 341),

e. Hydraulic System. The hydraulic system and the lubrication system use the same oil, operating from a common oil reservoir in the transmission. The oil also circulates through a cooling radiator and helps prevent excessive temperatures in the transmission. Figure 139 shows an engine with a cooling radiator attached which is used for cooling both engine oil and transmission oil. The radiator has separate cores for each. Actually, there are two separate radiators, one on each side of the engine, in the application shown. Each has separate cores for engine and transmission oil. The hydraulic system uses two separate valve systems for range and steering control.

(1) *Range control valve* (fig. 345). The range control valve consists essentially of a cylinder with a series of ports and a cylindrical valve that can be shifted into various positions by operation of the control lever in the driving compartment. When the valve is shifted, various ports are uncovered so that oil pressure is admitted, through the oil lines, to the different clutches. Oil pressure cannot be directed to more than one clutch at a time. In neutral, oil pressure is cut off from the low-range clutch, high-range clutch, and reverse-range clutch so that there is no drive to the output ring gears. However, steering in neutral range can be accomplished by operation of the steering valves as described in (5) below.

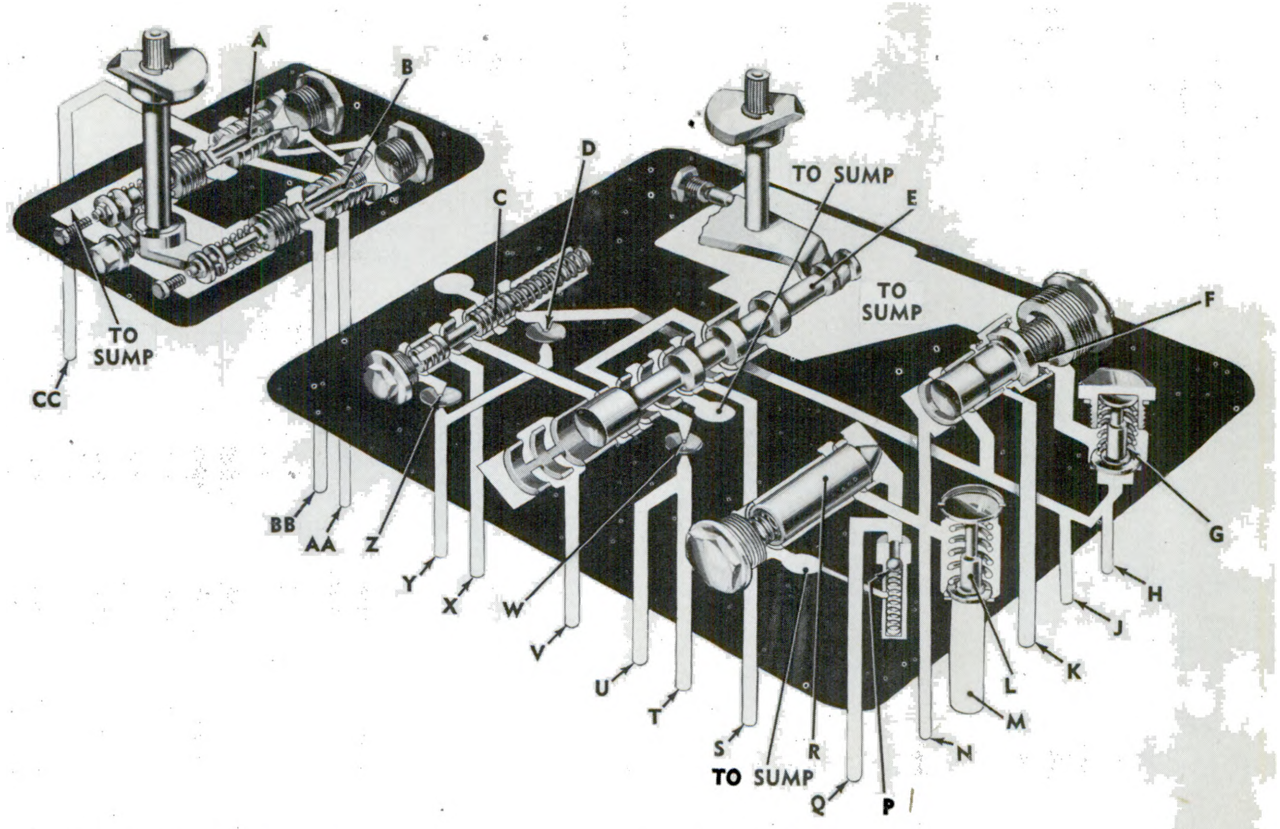
(2) *Low range.* When the range-control valve is shifted to low range, oil pressure is admitted to the low-range clutch (through line T, fig. 345). Oil pressure is cut off from the other range clutches. The low-range clutch engages and the power flow through the transmission is as shown in figure 339. Note that the low-range line is also connected to a low-range accumulator (through line U, fig. 345). The accumulator is simply a spring-loaded piston in a cylinder. The piston moves to compress the spring as oil pressure is admitted into the low-range clutch line. This provides a cushioning effect and softens the engagement of the low-range clutch, thereby preventing a sudden and jolting shift.

(3) *High range.* When the range-control valve is shifted to high range, oil pressure is admitted to the high-range clutch (through line S, fig. 345). Oil pressure is cut off from the other range clutches. The high-range clutch therefore engages


REAR
OUTPUT PLANETARY CARRIER ASSEMBLY
LOCK-UP CLUTCH
LEFT STEER CLUTCH
STEER DIFFERENTIAL
LEFT
RIGHT STEER CLUTCH
HIGH RANGE CLUTCH
BRAKE
REVERSE RANGE PLANETARY CARRIER ASSEMBLY
LOW RANGE PLANETARY CARRIER ASSEMBLY
TURBINE
FIRST STATOR
SECOND STATOR
PUMP
INPUT DRIVE
LEFT STEER — LOW RANGE
🟥 INPUT
☐ HYDRAULIC PATH
🟩 RIGHT OUTPUT (Speeded)
▨ LEFT OUTPUT (Slowed)
▨ RIGHT STEER PATH (Forward)
🟦 LEFT STEER PATH (Reverse)
▨ LEFT STEER PATH and LOW CLUTCHES ENGAGED
REVERSE RANGE CLUTCH
FRONT
LOW RANGE CLUTCH
RIGHT
BRAKE
OUTPUT PLANETARY CARRIER ASSEMBLY

RA PD 151768

Figure 344. Power flow in cross-drive transmission during left steering in low range.



A—RIGHT-STEERING VALVE
B—LEFT-STEERING VALVE
C—STEERING-OVERSPEED SAFETY VALVE
D—ORIFICE
E—RANGE CONTROL VALVE
F—CONVERTER-PRESSURE REGULATOR VALVE
G—LUBRICATION REGULATOR VALVE
H—TO LUBRICATING SYSTEM
J—TO STEERING-OVERSPEED LIMIT PUMP
K—TO CONVERTER LOCK-UP CLUTCH
L—COOLER BY-PASS VALVE
M—FROM CONVERTER
N—TO CONVERTER
P—MAIN-PRESSURE RELIEF VALVE
Q—MAIN PRESSURE
R—MAIN-PRESSURE REGULATOR VALVE
S—TO HIGH-RANGE CLUTCH
T—TO LOW-RANGE CLUTCH
U—TO LOW-RANGE ACCUMULATOR
V—TO REVERSE-RANGE CLUTCH
W—LOW-RANGE ORIFICE
X—MAIN PRESSURE
Y—FROM STEERING-OVERSPEED LIMIT PUMP
Z—ORIFICE
AA—MAIN PRESSURE
BB—TO LEFT-STEERING CLUTCH
CC—TO RIGHT-STEERING CLUTCH

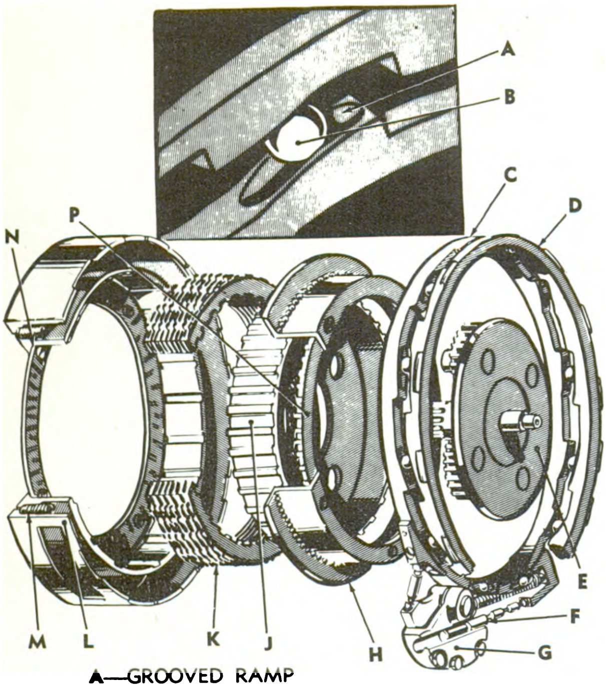
RA PD 151758

Figure 345. Range control valve and steering valves—schematic diagram.

and the power flow through the transmission is as shown in figure 340.

(4) *Reverse range.* When the range-control valve is shifted to reverse range, oil pressure is admitted to the reverse-range clutch (through line V, fig. 345). Oil pressure is cut off from the other range clutches. The reverse-range clutch therefore engages, and the power flow through the transmission is as shown in figure 341.

(5) *Steering valves.* The right-and-left steering valves (A and B, fig. 345), are operated by linkage from the driver's compartment. These valves are modulating-type valves, which means they are not simple "open-or-closed" valves but can be opened to admit more or less oil pressure to the steer clutches. The driver can vary the oil pressure to the steer clutches by varying the amount of pressure applied to the steering control. This in turn varies the amount of steering obtained. When a left steer is applied to the control, the left steering valve admits oil pressure to the left-steer clutch, to produce a left steer; the power flow through the transmission steering system being as shown in figures 342 and 344. When a right steer is applied to the control by the driver, the right steering valve



A—GROOVED RAMP
B—BRAKE APPLY BALL
C—{BRAKE APPLY CAM (ROTATING RING)
D—{BRAKE APPLY CAM (STATIONARY RING)
E—OUTPUT SHAFT
F—BRAKE LUBE VALVE
G—BRAKE APPLY MECHANISM
H—{BRAKE APPLY RING WITH 229 BALLS
J—OUTPUT PLANET CARRIER
K—BRAKE DISK PACK
L—BRAKE ANCHOR
M—RETURN SPRING
N—FIXED PRESSURE PLATE
P—FLOATING PRESSURE PLATE RA PD 151775

Figure 346. Brake—schematic view.

admits oil pressure to the right-steer clutch to produce a right steer.

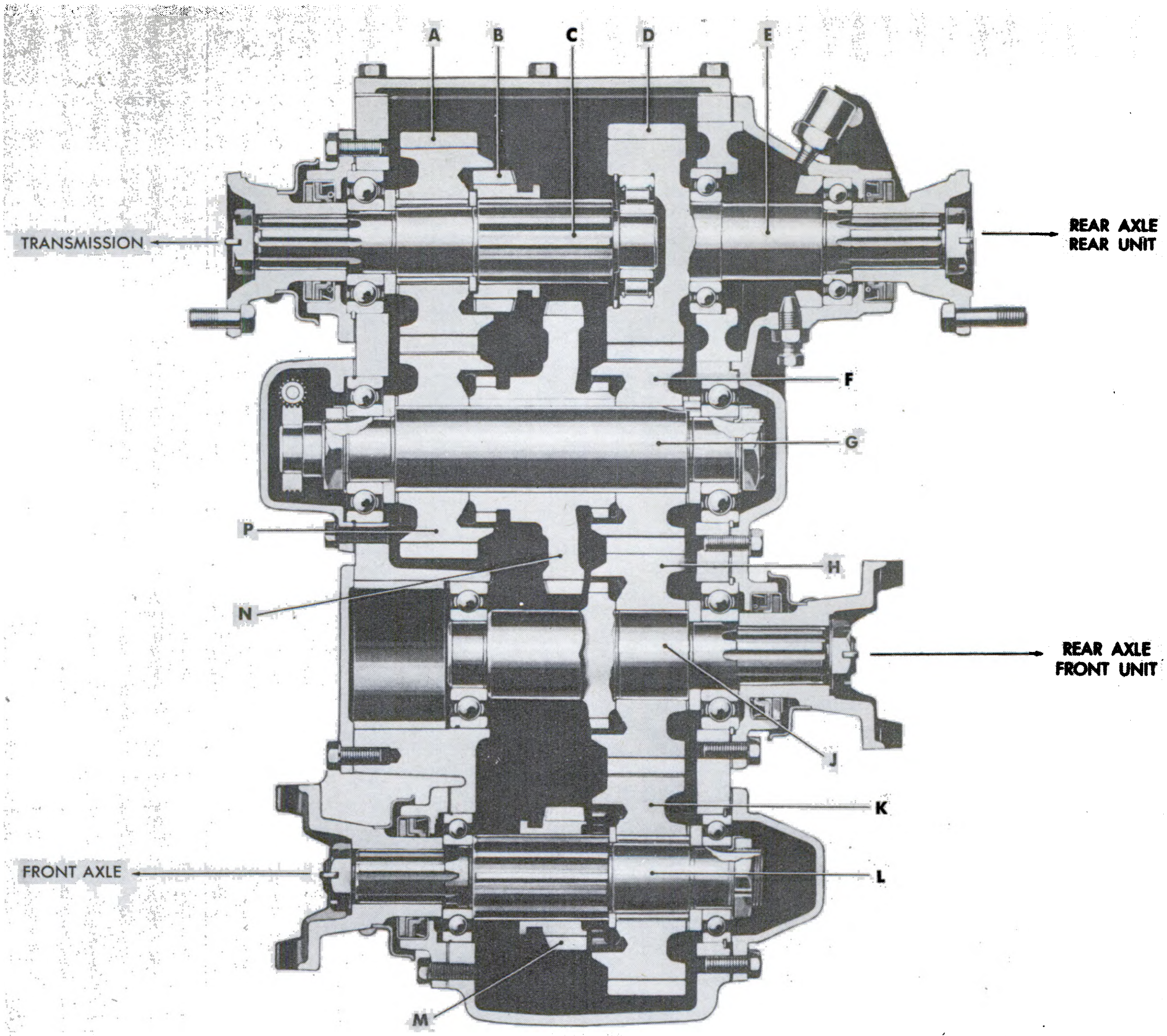
(6) *Pressure regulating valves* (fig. 345). The range control valve body also contains various pressure regulating valves. Main pressure from the oil pump is admitted to the valve body through line (Q). The main-pressure regulator valve (R) prevents excessive pressure while the main-pressure relief valve (P) opens to permit excessive oil to flow back to the oil reservoir. Oil pressure to the converter is regulated by valve (F) while oil pressure to the lubrication system is regulated by valve (G). Valve (L) is a cooler bypass valve which bypasses oil from the lubrication system and is not needed to maintain pressure. Valve (C) is a steering-overspeed safety valve which prevents excessive pressure to the steer clutches which would result in rapid steering.

(*f*) *Brakes.* Each of the two output planetary systems includes a friction disk brake assembly (fig. 346). Each assembly consists of six internally splined disks splined to the output planet carrier and five externally splined disks splined to the brake anchor. The brake anchor is bolted to the transmission end plate and is therefore stationary. Inside the brake anchor is a brake-apply cam-stationary ring. Next to the stationary ring is a brake-apply cam-rotating ring. A single brake pedal in the driver's compartment applies both brakes simultaneously. When a brake is applied, mechanical linkage causes the brake-apply shaft to rotate. This causes the brake-apply cam-rotating ring to rotate a few degrees, forcing the 12 brake-apply balls to roll up grooved ramps. Since these ramps are located between the two cam rings, the balls force the two rings apart. The stationary ring, being fastened to the anchor plate, cannot move, so the rotating ring must move. This movement compresses the disk pack through the brake-apply ring, thereby applying the brake. The same action takes place on both assemblies. When the brakes are released, the brake-apply mechanism rotates the rotating ring back to its original position so the pressure on the disk pack is relieved.

Section V. AUXILIARY EQUIPMENT

209. Transfer Assemblies

a. Purpose. With the addition of front wheels as driving members of a vehicle to supply more traction, the need for a transfer assembly became imperative. The transfer assembly (figs. 347 and 348), an auxiliary gear train on all-wheel-drive vehicles, enables the power to be divided or transferred to both forward and rear propeller shafts, and provides a means of lowering the power train components sufficiently to permit the forward propeller shaft to clear the engine crankcase. The transfer is essentially a two-speed transmission unit (low and direct drive), but may include an additional gear reduction. It is similar in mounting to the auxiliary transmission (par. 211).


A
B
C
D
E
TRANSMISSION
REAR AXLE
REAR UNIT
F
G
P
H
N
REAR AXLE
FRONT UNIT
J
K
FRONT AXLE
L
M

GEAR TRAIN

A—MAINSHAFT CONSTANT MESH GEAR
B—MAINSHAFT SLIDING GEAR
C—MAINSHAFT
D—REAR AXLE (REAR UNIT) DRIVE GEAR
E—REAR AXLE (REAR UNIT) DRIVE GEAR ASSEMBLY
F—IDLER SHAFT CONSTANT MESH GEAR
G—IDLER SHAFT
H—DRIVE SHAFT CONSTANT MESH GEAR
J—REAR AXLE (FRONT UNIT) DRIVE SHAFT
K—DRIVE SHAFT CONSTANT MESH GEAR
L—FRONT AXLE DRIVE SHAFT
M—DRIVE SHAFT SLIDING GEAR
N—IDLER SHAFT LOW SPEED GEAR
P—IDLER SHAFT CONSTANT MESH GEAR

RA PD 183950

Figure 347. Transfer assembly—cross sectional view.

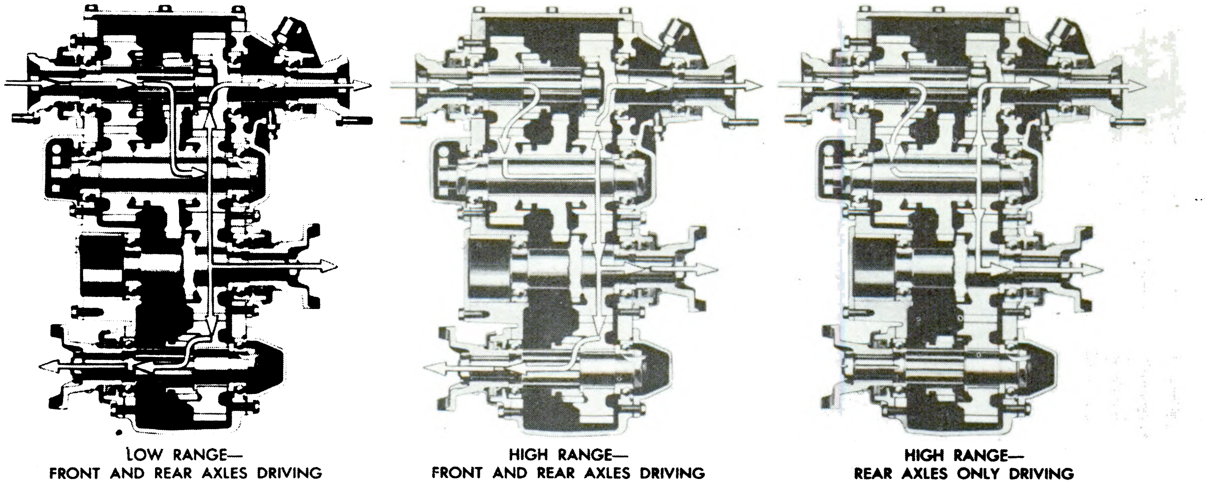


Figure 348. Transfer assembly power flow shown by arrows.

b. Operation.

(1) In the high ratio (1:1), when driving both the front and rear axles, the external teeth of the sliding gear (splined to the transmission main shaft) are in mesh with the internal teeth of the constant mesh gear mounted on this shaft. Likewise, the external teeth of the front-axle sliding gear are in mesh with internal teeth on the constant-mesh gear or the sliding clutches are engaged. Disengagement of the drive to the front axle is accomplished by shifting the sliding gear on the front-axle main shaft out of mesh with the constant-mesh gear, permitting the latter to roll free on the shaft, or sliding the clutches out of mesh.

(2) When using the low ratio in the transfer assembly, the sliding gear on the transmission main shaft is disengaged from the constant-mesh gear and engaged with the idler gear on the idler shaft. This reduces the speed by having the sliding gear mesh with the larger idler gear. The shifting linkage on some vehicles is so arranged that shifting into the low range is possible only when the drive to the front axle is engaged. This prevents the driver from applying maximum torque to the rear drive only, which might cause damage.

c. Power Take-Off Units. These are discussed in chapter 24.

210. Transfer Assemblies With Overrunning Sprag Units

a. Purpose. Some transfers contain an overrunning sprag unit (or units) on the front output shaft. On these units the transfer is designed to drive the front axle slightly slower than the rear axle. During normal operation, when both front and rear wheels turn at the same speed, only the rear wheels drive the vehicle. However, if the rear wheels should lose traction and begin to slip, they tend to turn faster than the front wheels. As this happens, the sprag unit automatically engages so that the front wheels also drive the vehicle. The sprag unit simply provides an automatic means of engaging the front wheels in drive whenever additional tractive effort is required. There are two types of sprag-unit-equipped transfers, a single-sprag-unit transfer and a double-sprag-unit transfer. Essentially, both types work in the same manner.

b. Sprag-Unit Construction and Operation.

(1) *Transfer assembly.* The transfer assembly is very similar to that described in paragraph 209, the essential difference being that a sprag unit has been substituted for the hand-operated sliding clutch on the front output shaft. The sprag unit acts as an overrunning clutch, permitting the front wheels to turn freely at the same speed as the rear wheels, but locking up to drive the front wheels when the rear wheels tend to turn faster

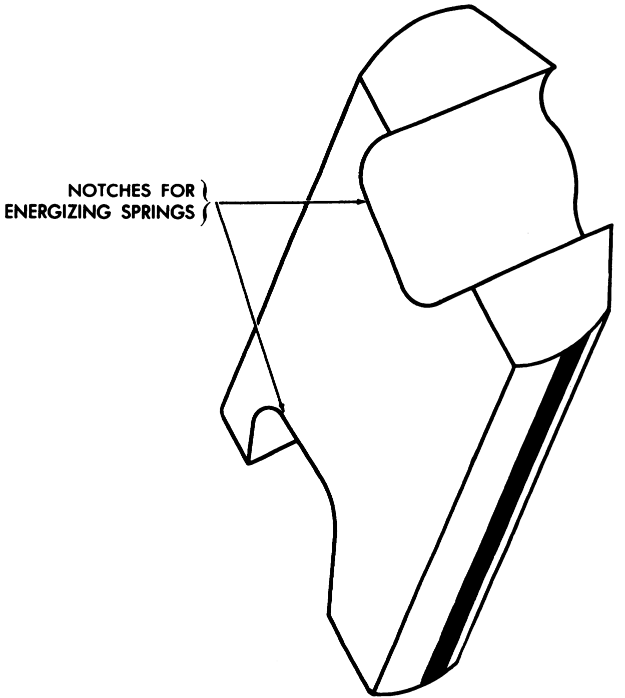


Figure 349. Sprag.

than the front wheels (as when the rear wheels lose traction and slip).

(2) *Sprag.* A sprag (fig. 349) is a steel block so shaped as to act as a wedge in the complete assembly. In the sprag unit under discussion, there are 42 sprags assembled into an outer race and held in place by two energizing springs (fig. 350). The springs fit into the notches in the ends of the sprags and hold them in position. The outer race is in the driven gear on the front output shaft. The inner race is on the front output shaft itself.

(3) *Single-sprag-unit operation.* During normal operation, when front and rear wheels of the vehicle are turning at the same speed, the outer race of the sprag unit (in the driven gear) turns a little slower than the inner race (on the front output shaft). This prevents the sprags from wedging between the races (fig. 351). No lockup occurs and the front wheels turn freely; they are not driven. However, if the rear wheels should lose traction and tend to turn faster than the front wheels, the outer race tends to turn faster than the inner race. When this happens, the sprags wedge or jam between the two races and the races turn as a unit to provide driving power to the front wheels. Just as soon as the rear wheels regain traction so that they slow down to front-wheel speed, the outer race slows down in relation to the inner race and the sprag-unit releases. The action is shown schematically in figure 352.

(4) *Single-sprag-unit operation in reverse.* In reverse, it is necessary to lock out the single-sprag unit, since rotation is reversed, and this means that no driving can be achieved through the sprag units at all. Lockout is accomplished through a linkage to the transmission that shifts a reverse-shift collar in the transfer. As the reverse-shift collar is shifted, internal splines in the collar mesh with external splines on the reverse-shift driven gear and on the front output driven gear so there is a solid drive around the sprag unit.

(5) *Double-sprag unit.* The double-sprag unit operates the same way as the single-sprag unit in forward speeds. In reverse, however, the difference between the two units becomes apparent. In the double-sprag unit, a second sprag unit has been included which comes into operation only in reverse. When the shift is made to reverse, the forward sprag unit is locked out, almost exactly as described in (4) above for the single-sprag unit. However, the reverse sprag unit comes into operation. The front wheels drive, in reverse, when the rear wheels lose traction and tend to revolve faster than the front wheels. The shift from one sprag unit to the other is accomplished by a linkage to the transmission that shifts a reverse-shift collar in the transfer. As the reverse-shift collar is shifted, internal splines in the collar unmesh from the external splines on the outer race of one sprag unit and mesh with the external splines on the other sprag unit.

c. Air-Controlled Double-Sprag Unit.

(1) *General.* Figure 353 shows the power flow in the transfer unit using the air-controlled double-sprag unit described in

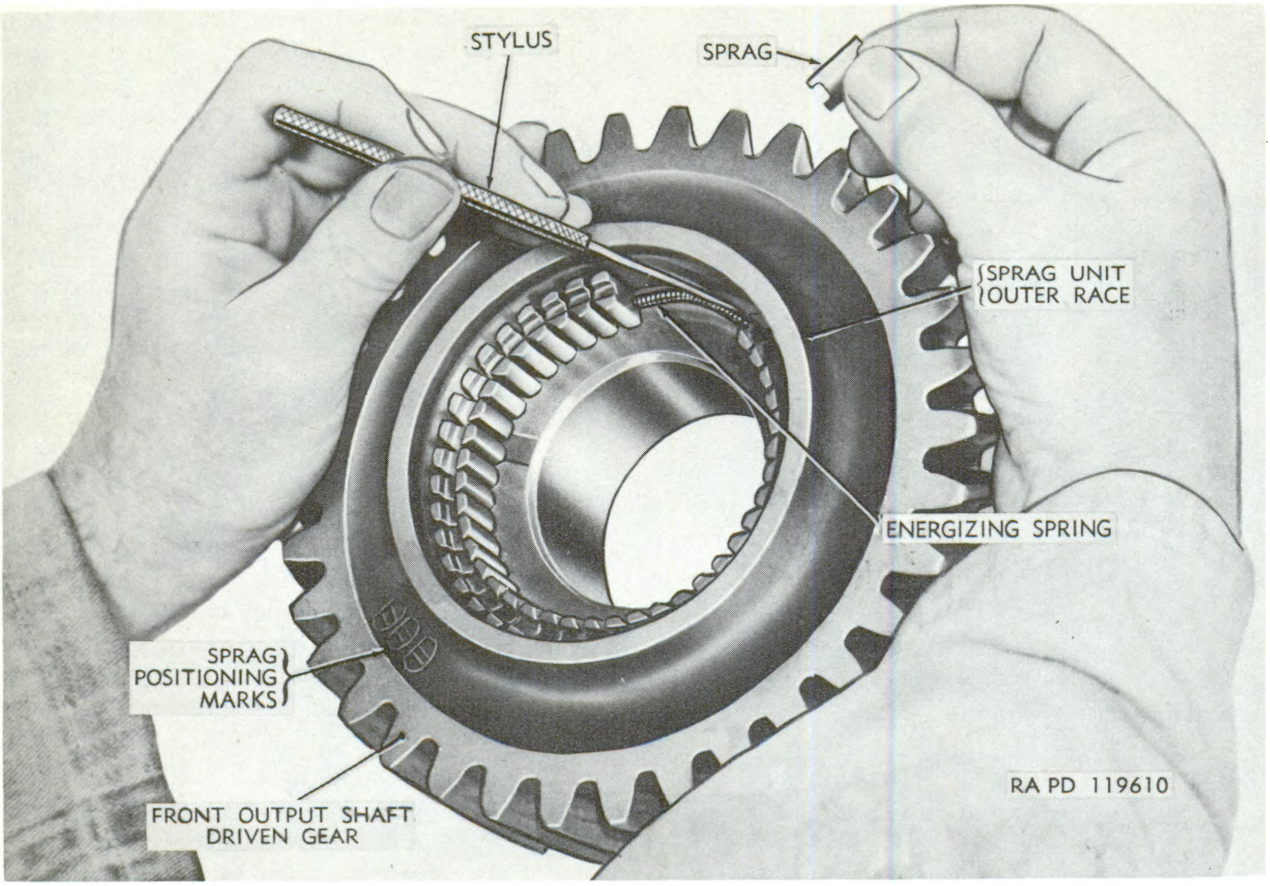

STYLUS
SPRAG
SPRAG UNIT OUTER RACE
ENERGIZING SPRING
SPRAG POSITIONING MARKS
FRONT OUTPUT SHAFT DRIVEN GEAR
RA PD 119610

Figure 350. Assembling sprags into outer race in the front output shaft driven gear.

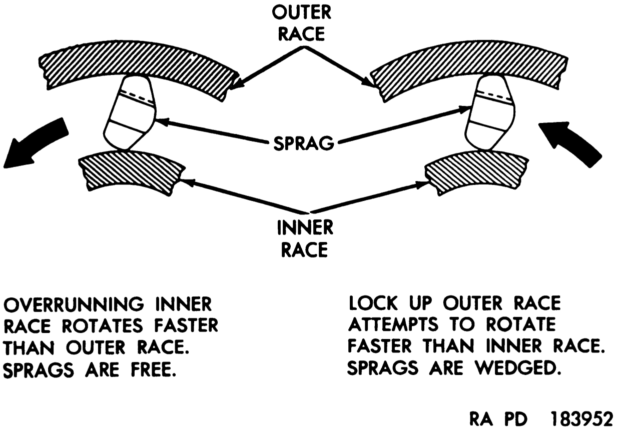
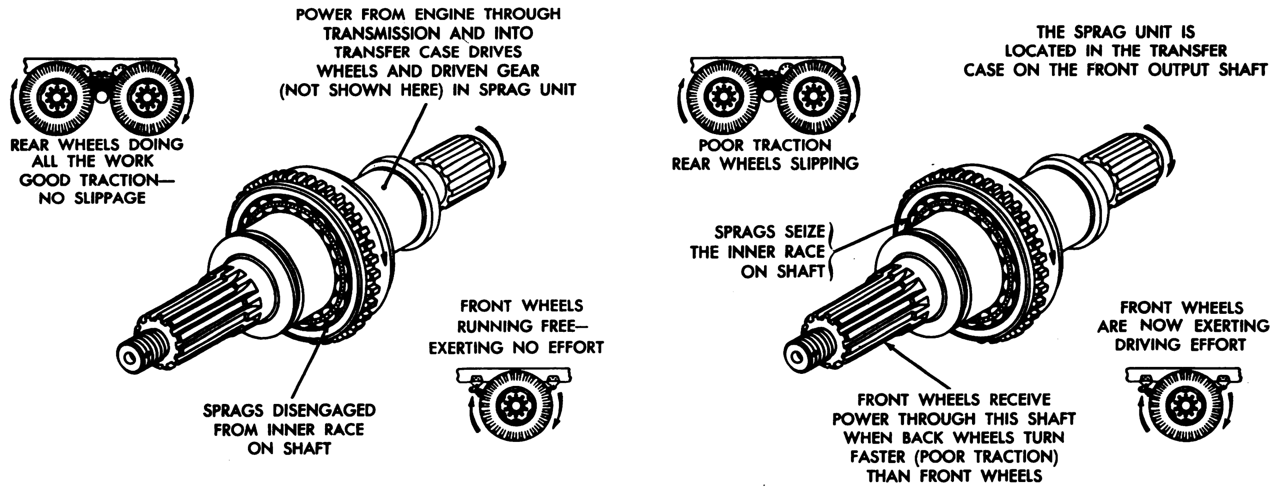

OUTER RACE
SPRAG
INNER RACE
OVERRUNNING INNER RACE ROTATES FASTER THAN OUTER RACE. SPRAGS ARE FREE.
LOCK UP OUTER RACE ATTEMPTS TO ROTATE FASTER THAN INNER RACE. SPRAGS ARE WEDGED.
RA PD 183952

Figure 351. Sprag unit overrunning and locked up.

(2) below. The double-sprag unit has the same function as that described in *b* (5) above, the essential difference being that there is an air valve on the transmission low- and reverse-shifter shaft, which automatically shifts the sprag unit to forward or reverse whenever the main transmission is shifted to forward or reverse.

(2) *Construction and operation.* Figure 354 is the air-control diagram of the transmission and transfer assembly using an air-controlled double-sprag unit. When the transmission is in neutral or a forward gearshift position, and there is compressed air in the compressed air system of the vehicle, the air cylinder control valve (A, fig. 354) will be so positioned as to admit air under pressure from the compressed air system into the shift air cylinder assembly (H, fig. 354). The air is then admitted to the forward-shift side of the spring-balanced piston in the cylinder. The piston is thereby moved and causes engagement of the forward sprag unit. When the transmission is shifted into reverse, the air cylinder control valve admits air to the opposite side of the piston, causing engagement of the reverse sprag unit. When the forward sprag unit is engaged, the front wheels will freewheel or turn only in a forward direc-

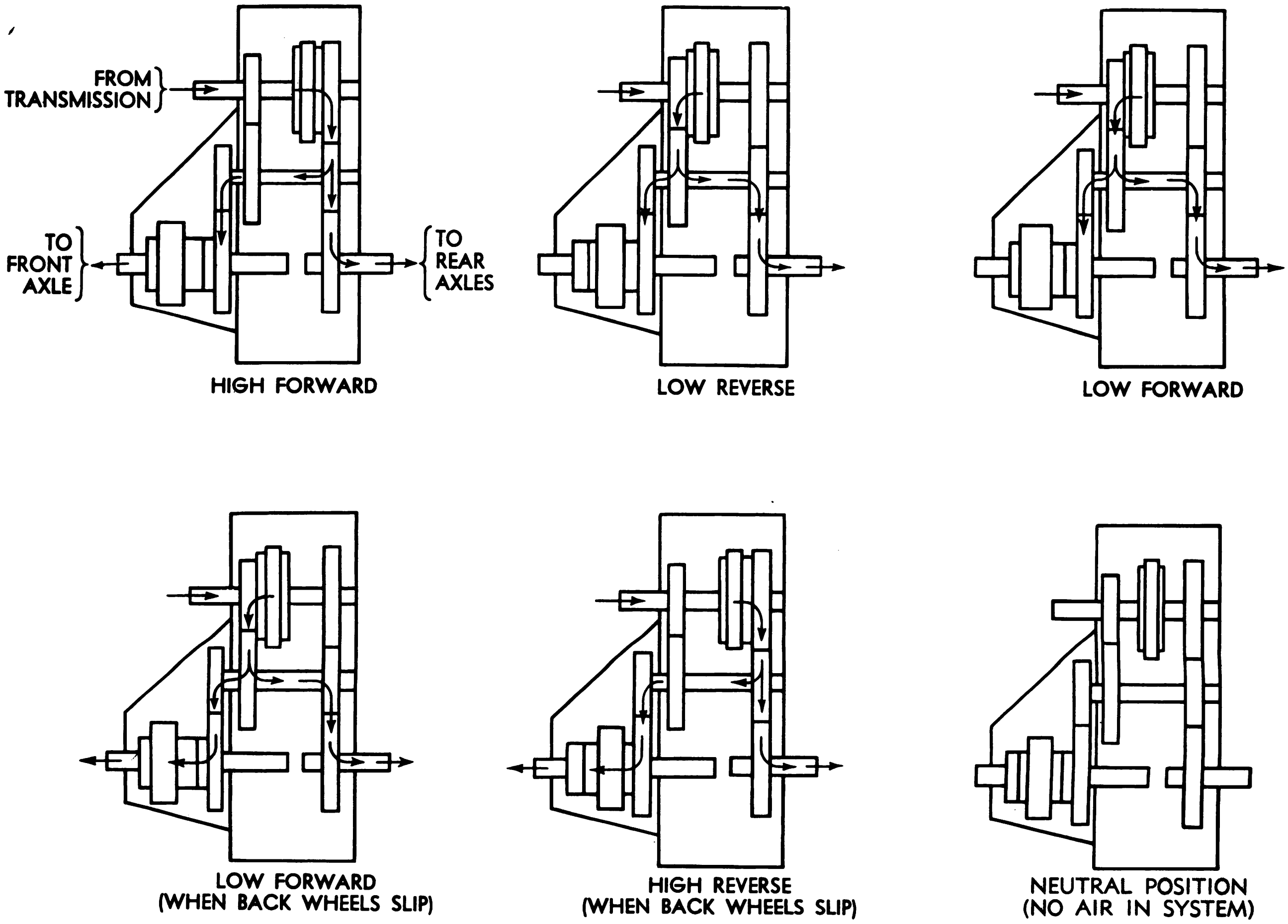

POWER FROM ENGINE THROUGH TRANSMISSION AND INTO TRANSFER CASE DRIVES WHEELS AND DRIVEN GEAR (NOT SHOWN HERE) IN SPRAG UNIT
REAR WHEELS DOING ALL THE WORK GOOD TRACTION—NO SLIPPAGE
FRONT WHEELS RUNNING FREE—EXERTING NO EFFORT
SPRAGS DISENGAGED FROM INNER RACE ON SHAFT
THE SPRAG UNIT IS LOCATED IN THE TRANSFER CASE ON THE FRONT OUTPUT SHAFT
POOR TRACTION REAR WHEELS SLIPPING
SPRAGS SEIZE THE INNER RACE ON SHAFT
FRONT WHEELS ARE NOW EXERTING DRIVING EFFORT
FRONT WHEELS RECEIVE POWER THROUGH THIS SHAFT WHEN BACK WHEELS TURN FASTER (POOR TRACTION) THAN FRONT WHEELS

1. FRONT WHEELS RUNNING FREE

2. FRONT WHEELS DRIVING

RA PD 183953

Figure 352. Principle of sprag-unit action.


FROM TRANSMISSION
TO FRONT AXLE
TO REAR AXLES

HIGH FORWARD

LOW REVERSE

LOW FORWARD

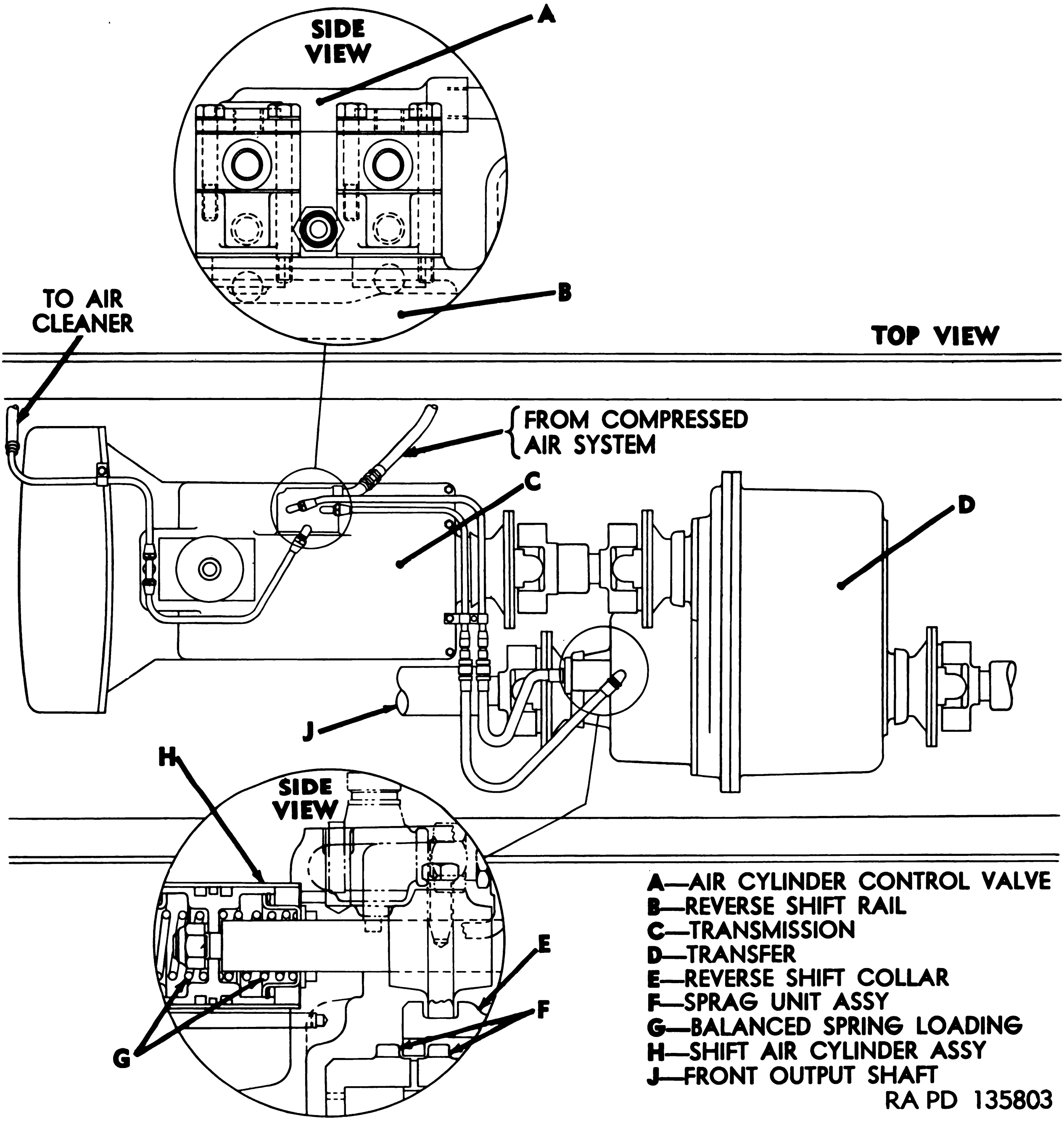
LOW FORWARD (WHEN BACK WHEELS SLIP)

HIGH REVERSE (WHEN BACK WHEELS SLIP)

NEUTRAL POSITION (NO AIR IN SYSTEM)

RA PD 135802

Figure 353. Power flow diagram through transfer.


SIDE VIEW
A
B
TO AIR CLEANER
TOP VIEW
FROM COMPRESSED AIR SYSTEM
C
D
J
H
SIDE VIEW
E
F
G

A—AIR CYLINDER CONTROL VALVE
B—REVERSE SHIFT RAIL
C—TRANSMISSION
D—TRANSFER
E—REVERSE SHIFT COLLAR
F—SPRAG UNIT ASSY
G—BALANCED SPRING LOADING
H—SHIFT AIR CYLINDER ASSY
J—FRONT OUTPUT SHAFT

RA PD 135803

Figure 354. Air control diagram of transmission and transfer assembly using an air-controlled double-sprag unit.

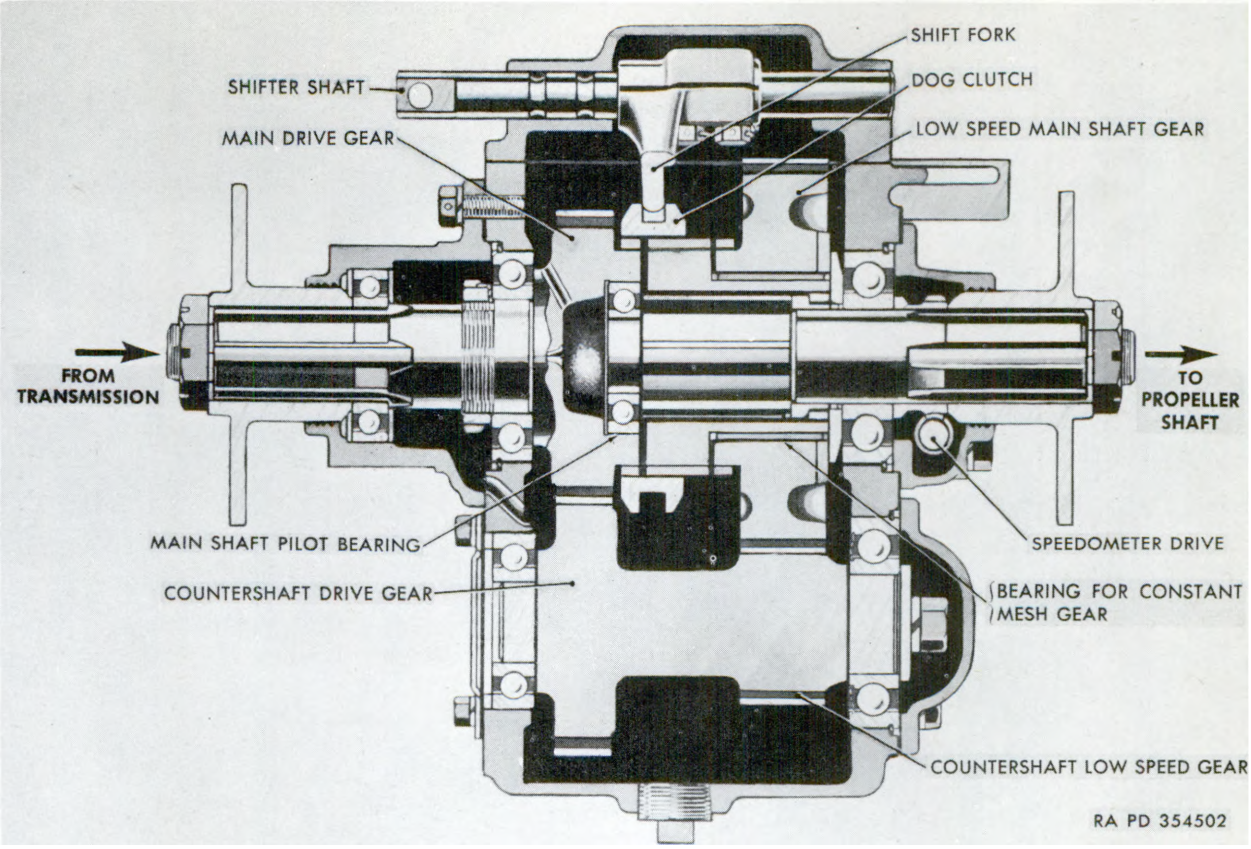

SHIFT FORK
SHIFTER SHAFT
DOG CLUTCH
MAIN DRIVE GEAR
LOW SPEED MAIN SHAFT GEAR
FROM TRANSMISSION
TO PROPELLER SHAFT
MAIN SHAFT PILOT BEARING
SPEEDOMETER DRIVE
COUNTERSHAFT DRIVE GEAR
BEARING FOR CONSTANT MESH GEAR
COUNTERSHAFT LOW SPEED GEAR
RA PD 354502

Figure 355. Auxiliary transmission—sectional view.

tion. Likewise, if the reverse sprag unit is engaged, the front wheels cannot be turned in a forward direction. Also, if a vehicle with air pressure in the system is parked with the transmission shift lever in neutral position, it cannot be pushed backward until the transmission shift lever is shifted to reverse.

211. Auxiliary Transmission

(fig. 355)

Auxiliary transmissions are mechanisms mounted in the rear of the regular transmission to provide an increased number of gear ratios. The types most commonly used, normally have only a low and a high (direct) range, incorporated into a transfer assembly. The low range provides an extremely low gear ratio on hard pulls. At all other times the high range is used, the power merely passing through the main shaft. Gears are shifted by a separate gearshift lever in the driver's cab.

212. Multiple-Speed Subtransmission

Multiple-speed subtransmissions are used only on the heavier trucks. They usually consist of some device similar to an auxiliary transmission, which is built into the regular transmission.

213. Overdrives

a. Planetary Gears. A knowledge of planetary gears, a form of gear train ordinarily used to obtain speed reductions, is necessary before the overdrive mechanism can be understood. These gears consist of three elements as described in paragraph 187*e*.

b. Function. A transmission overdrive (fig. 356) provides a gear ratio less than 1:1. It reduces oil consumption and engine wear by requiring less revolutions of the engine for a given mileage than required if direct drive is used, and reduces gasoline consumption by providing a more suitable gear ratio for high speeds on level roads. When in operation, the overdrive reduces the engine rear-axle gear ratio by approximately 30 percent. A freewheeling device is usually incorporated in the overdrive, which also helps to save gasoline. The overdrive is usually a separate unit bolted to the rear of the transmission case. In some transmissions, an overdrive is obtained by the gear ratios provided in the transmission.

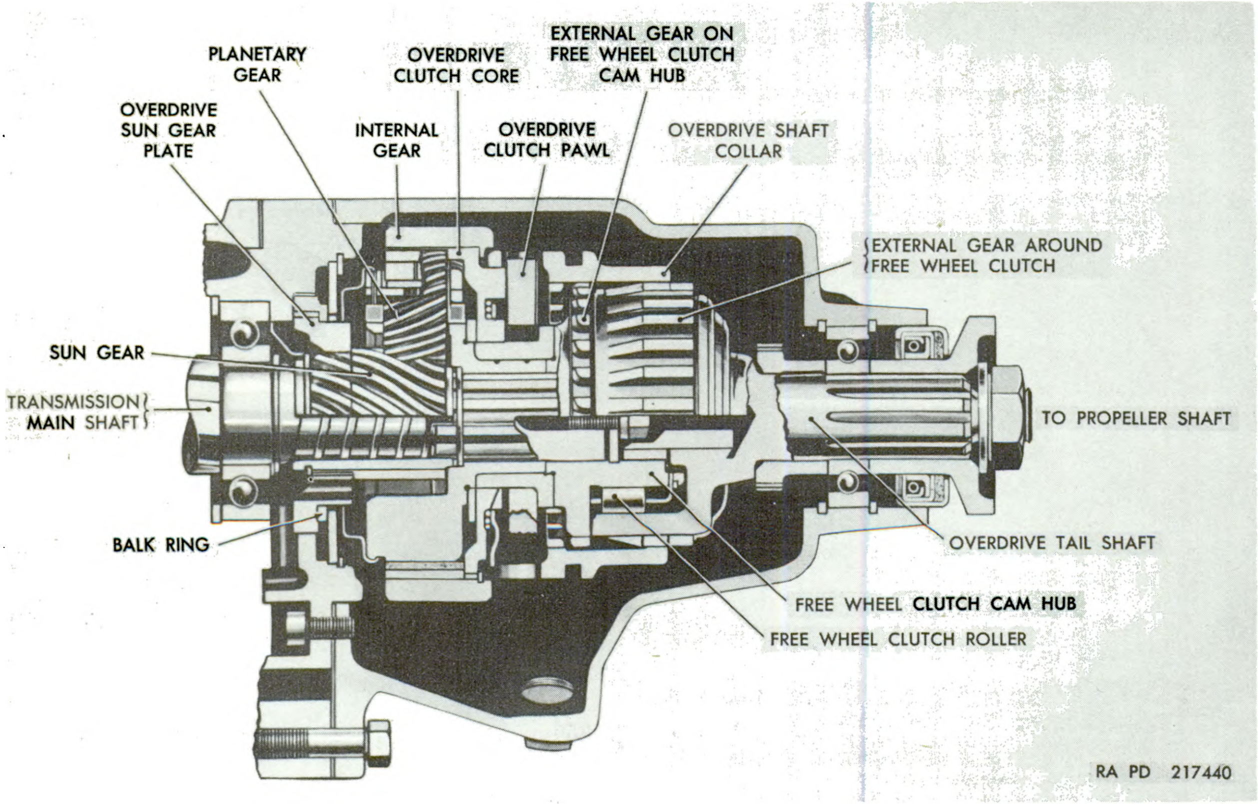

EXTERNAL GEAR ON FREE WHEEL CLUTCH CAM HUB
PLANETARY GEAR
OVERDRIVE CLUTCH CORE
OVERDRIVE SUN GEAR PLATE
INTERNAL GEAR
OVERDRIVE CLUTCH PAWL
OVERDRIVE SHAFT COLLAR
EXTERNAL GEAR AROUND FREE WHEEL CLUTCH
SUN GEAR
TRANSMISSION MAIN SHAFT
TO PROPELLER SHAFT
BALK RING
OVERDRIVE TAIL SHAFT
FREE WHEEL CLUTCH CAM HUB
FREE WHEEL CLUTCH ROLLER
RA PD 217440

Figure 356. Overdrive unit—cross sectional view.

CHAPTER 16

PROPELLER SHAFTS, SLIP JOINTS, AND UNIVERSAL JOINTS

214. Propeller Shafts and Slip Joints

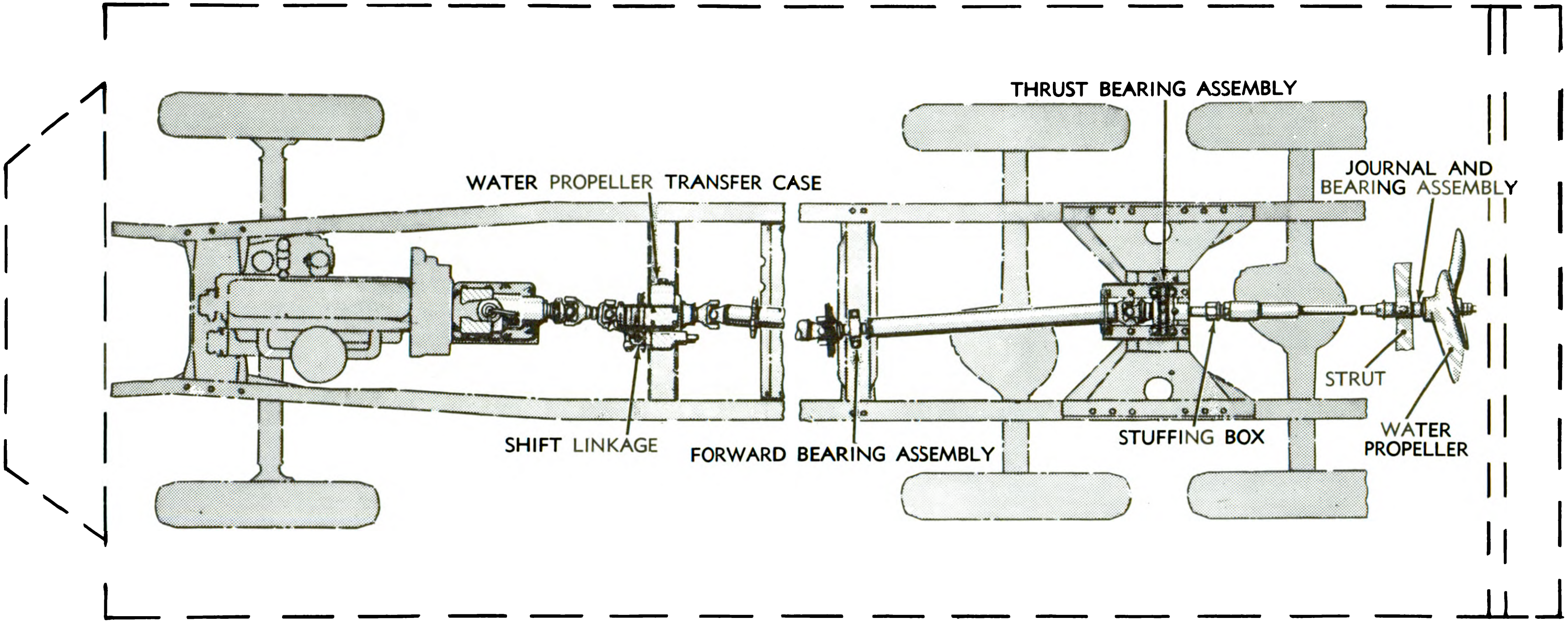
a. Propeller Shafts. The power, having been transmitted through an angle by means of a universal joint, is next carried along the power train by a device known as a *propeller*, or *drive*, *shaft* (figs. 284, 285, 357, and 358). Propeller shaft is the most common term; however, either may be used. In amphibious vehicles both terms are used: propeller shaft to indicate the device which transmits power to the propeller, and drive shaft to indicate that which transmits power to the wheels. Propeller shafts may be the solid or the tubular type. The torsional stress in a shaft varies from zero at the axis to a maximum at the outside. Since the center of the shaft resists only a small portion of the load, hollow shafts are used wherever practicable. A solid shaft is somewhat stronger than a hollow shaft of the same diameter, but a hollow shaft is much stronger than a solid shaft of the same weight.

b. Propeller Shaft Drive in Amphibious Vehicles. On an amphibious truck, the drive for the water propeller is from a water propeller transfer case. This transfer case is connected to the transmission through a short propeller shaft. Transmission speeds used in water operation are transmitted through the water propeller transfer case, then to the water propeller by a drive line consisting of three drive shafts (fig. 357). Front and center drive shafts are of the tubular type, while the rear shaft is of solid construction. The drive shafts are connected by universal joints. A hand crank wheel, used as an auxiliary means for starting the engine, is welded onto the forward end of the front drive shaft tube. A bilge pump drive sprocket is mounted between the water propeller front- and center-drive shafts. The rear-drive shaft is tapered at the end to accommodate the water propeller. Two ball bearing assemblies are used to support the water propeller drive shaft, in addition to the babbitted bearing at the strut. A single-row ball bearing, mounted in a support bracket, is installed on the forward end of the center-drive shaft, and a thrust bearing is installed on the forward end of the rear-drive shaft. The driving force of the vehicle is transmitted to the water propeller through the thrust bearing which is mounted in a spherical-shaped chamber in the thrust bearing housing. A stuffing box with a replaceable rawhide packing in an adjustable gland is used at the point where the drive shaft passes through the hull. The stuffing box is attached to the hull tunnel tube by a hose, clamped in position.

c. Slip Joints. Because flexing of the springs causes the axle housing to move forward and backward, some provision must be made to allow the propeller shaft to contract and expand. A device known as a *slip joint* provides the necessary telescopic action for the propeller shaft. A slip joint consists of a male and female spline, a grease seal, and a lubrication fitting. The male spline is an integral part of the propeller shaft (fig. 358) and the female portion is fixed to the universal joint directly behind the transmission or transfer case. As the axle housing moves forward and backward the slip joint gives freedom of movement in a horizontal direction and yet is capable of transmitting rotary motion.

215. Conventional Universal Joint

a. Definition. A universal joint is a flexible coupling between two shafts that permits one shaft to drive another at an angle to it. It is flexible in the sense that it will permit power to be transmitted while the angle between the shaft is being continually varied. A simple universal joint illustrated in figure 359 is composed of three fundamental units: one journal and two yokes. The two yokes are set at right angles to each other, and their open ends are joined by the journal. This construction permits each yoke to pivot on the axis of the journal and also permits the transmission of the rotary motion from one yoke to the other. As a result, the universal joint can transmit the power from the engine through the shaft


WATER PROPELLER TRANSFER CASE
THRUST BEARING ASSEMBLY
JOURNAL AND BEARING ASSEMBLY
STRUT
WATER PROPELLER
STUFFING BOX
FORWARD BEARING ASSEMBLY
SHIFT LINKAGE

RA PD 316778

Figure 357. Propeller shaft installations in amphibious vehicle.

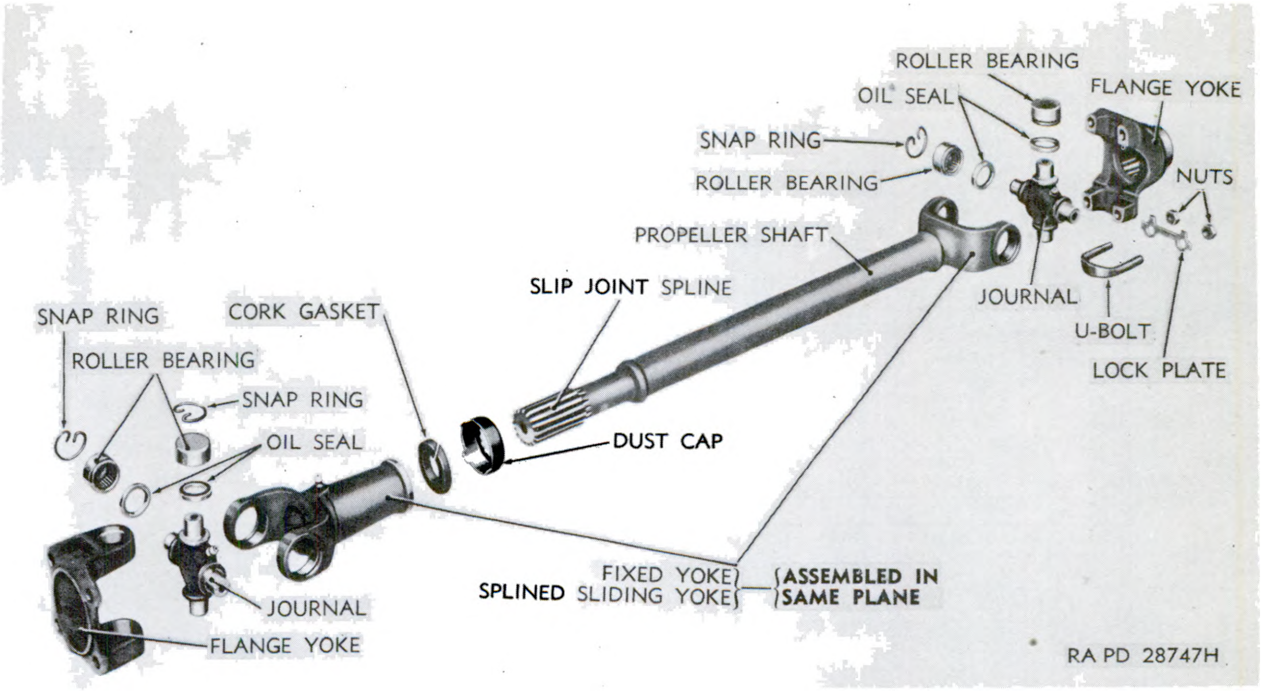

ROLLER BEARING
OIL SEAL
FLANGE YOKE
SNAP RING
ROLLER BEARING
NUTS
PROPELLER SHAFT
SLIP JOINT SPLINE
JOURNAL
U-BOLT
LOCK PLATE
SNAP RING
CORK GASKET
ROLLER BEARING
SNAP RING
OIL SEAL
DUST CAP
FIXED YOKE
SPLINED SLIDING YOKE
ASSEMBLED IN SAME PLANE
JOURNAL
FLANGE YOKE
RA PD 28747H

Figure 358. Propeller shaft and universal joints disassembled.

to the rear axle, even though the engine is rigidly mounted in the frame at a higher level than the rear axle, which is constantly moving up and down in relation to the frame.

b. Characteristics of Operation. A peculiarity of the conventional universal joint is that it causes a driven shaft to rotate at a variable speed in respect to the driving shaft. It has been found that there is a cyclic variation, in the form of an acceleration and a deceleration of the speed, twice during each revolution. The extent of such fluctuation depends on the amount of angularity, roughly about 7 percent for an angle of 15°, and about 30 percent for an angle of 30°. This fact is shown graphically in figure 360, where the variations of the angular velocity during one revolution of a shaft driven through a conventional universal joint are plotted. The driving shaft is running at a constant velocity of 1,000 rpm, and the angle between the shafts is 30°. Sketches of the universal joint positions at the minimum and maximum velocity fluctuation points are placed above the corresponding portions of the curve to enable the reader to correlate the curve with the action of the yoke and journal, of the universal joint.

(1) In a quarter of a revolution, the speed of the driven shaft varies from a minimum of 866 to a maximum of 1,155 rpm. The speed of the driven shaft equals that of the driving shaft at four points during the revolution; that is, 45°, 135°, 225°, and 315°, where the curve intersects the constant velocity (dotted) line. The extent of each fluctuation depends on the size of the angle between the shafts; the greater the angle, the greater the variation in the speed of the two shafts.

(2) This variation of velocity cannot be eliminated with a simple universal joint, but its effect can be minimized by using two universal joints (one at each end of the shaft). If only one joint is used between the transmission and the rear axle, the acceleration and deceleration caused

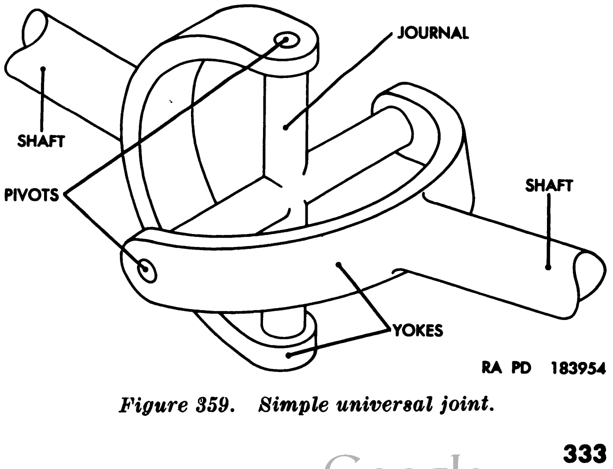
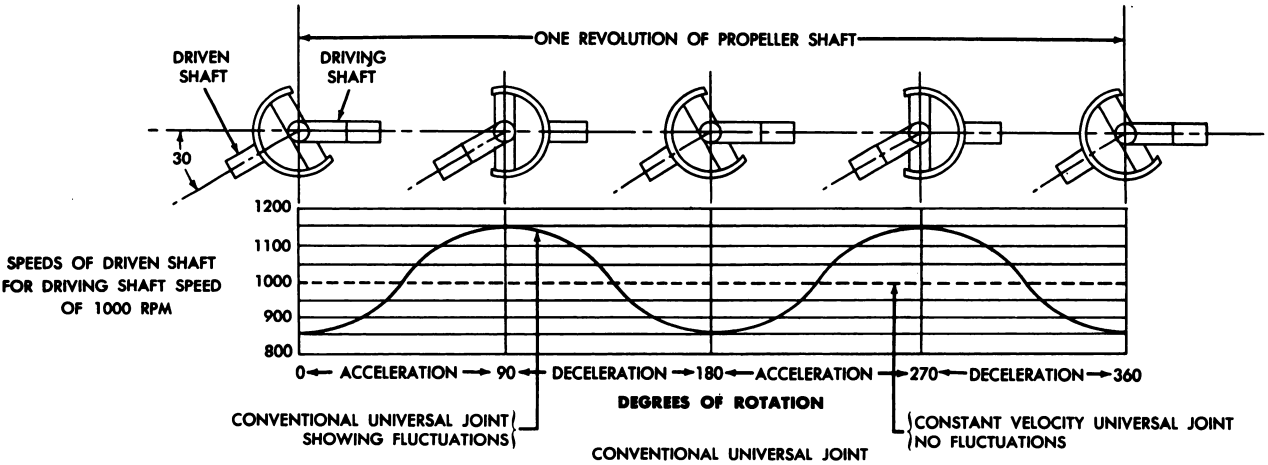

JOURNAL
SHAFT
PIVOTS
SHAFT
YOKES
RA PD 183954

Figure 359. Simple universal joint.



SHAFT ANGLE IN DEGREES	8	10	15	20	25	30	40
MAXIMUM VARIATION IN DRIVEN SHAFT SPEED PERCENT	2	3	6.9	12.4	19.7	28.9	54

RA PD 183955

Figure 360. Speed fluctuations caused by conventional joints.

by the joint is resisted on one end by the engine and on the other end by the inertia of the vehicle. The combined action of these two forces produces great stress on all parts of the power train and, in addition, results in a nonuniform force being applied to the wheels. When two universal joints are employed, the second joint is used to compensate for the speed fluctuations caused by the first. In order to accomplish this, the angle between the transmission shaft and the propeller shaft must be the same as the angle between the propeller shaft and the final drive of the rear axle. Another requirement is that the two yokes of the universal joint which are attached to the propeller shaft be in the same plane. If the yokes of the joints attached to the propeller shaft are in the same plane, the driving yoke of the first joint will be at an angle of 90° with the driving yoke of the second. The two yokes attached to the propeller shaft act as the driven yoke of the first joint and the driving yoke of the second joint respectively (fig. 358). With this arrangement, the first joint is producing its maximum fluctuation at the same time the second joint is producing its minimum fluctuation. This results in a nonvarying wheel speed for a given engine speed, even though the speed of the shaft between the joints is constantly changing.

c. Types.

(1) *General.* In an actual universal joint, bearings are included at the four points where the journal is attached to the yokes. In addition, one of the yokes usually incorporates a splined slip joint. In one type universal joint (the ball-and-trunnion type), the universal joint itself incorporates a feature that permits variations in length of the propeller shaft. Different types of universal joints are discussed in (2) and (3) below.

(2) *Journal-type universal joint.* There are several variations of this type of universal joint, two of which are shown in figures 361 and 362. The different universal joints of this type vary from each other mainly in the manner in which the journal is attached to the driving and driven yokes. For example, in the universal joint shown in figure 361, the journal is assembled in the shaft and slip yokes, the bearing assemblies inserted from the outside and secured by spring bearing retainers inside the yokes. The bearings on the transverse ends of the journal are clamped to the flange yokes and secured from outward movement by bearing retainers. The universal joint shown in figure 362 differs from that

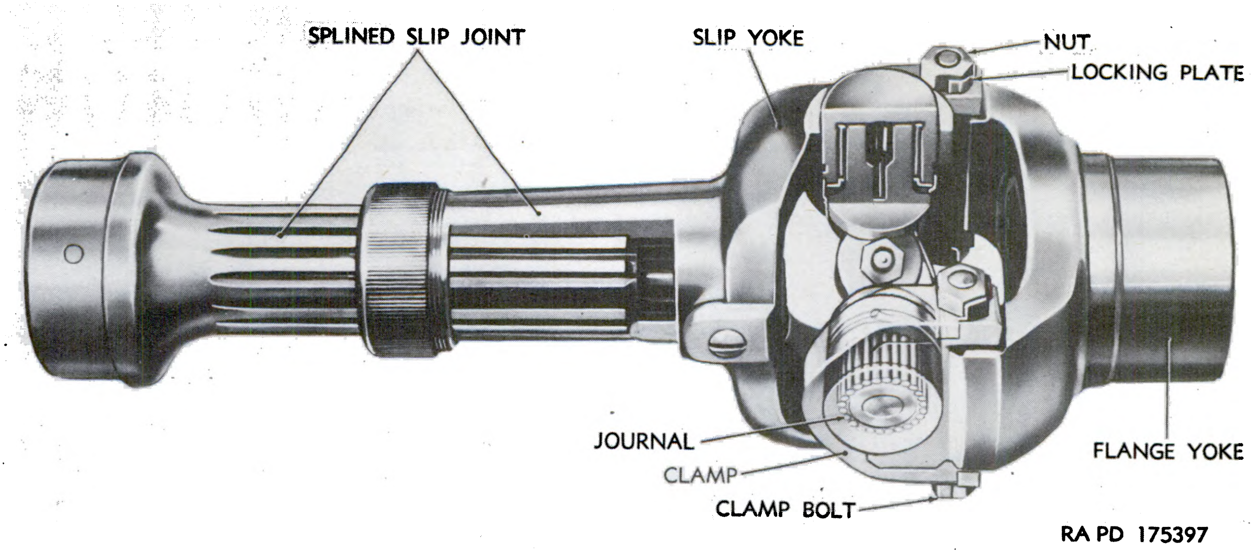

SPLINED SLIP JOINT
SLIP YOKE
NUT
LOCKING PLATE
JOURNAL
CLAMP
CLAMP BOLT
FLANGE YOKE
RA PD 175397

Figure 361. Universal joint—partial cutaway view.

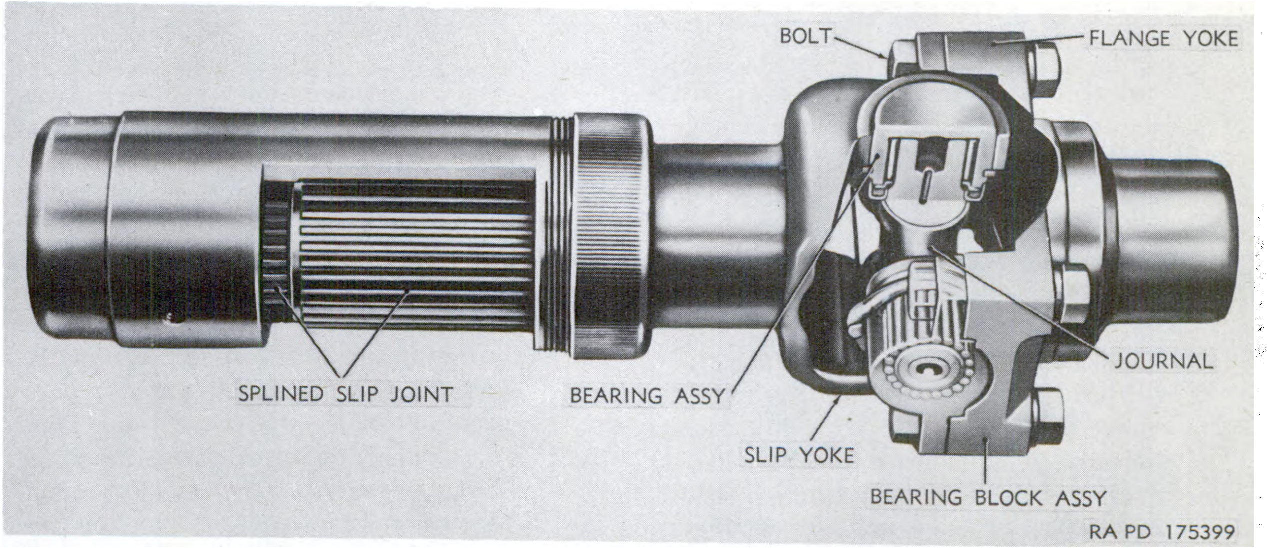

BOLT
FLANGE YOKE
SPLINED SLIP JOINT
BEARING ASSY
JOURNAL
SLIP YOKE
BEARING BLOCK ASSY
RA PD 175399

Figure 362. Universal joint—partial cutaway view.

shown in figure 361 in the manner in which the journal is attached to the flange yoke. In this universal joint, the bearing assembly is contained in bearing blocks. The blocks are mounted against the flange yokes and secured with bolts extending longitudinally through the yokes.

(3) *Ball-and-trunnion type.* Two universal joints of the ball-and-trunnion type are used in an application, one on each end of the propeller shaft. This type joint is shown in figures 363, 364, and 365. There is a trunnion pin through the end of the propeller shaft. The pin is fitted with balls which ride in grooves in the flanged body. The balls are assembled on bearings so they can rotate with little friction. Compensated springs at each end of the propeller shaft hold it in a centered position. Variations in length are permitted by the longitudinal movement of the balls in the body grooves, and angular displacement is allowed by outward movement of the balls on the trunnion pins. This type universal joint is easily recognized by the flexible dust boot that covers it. The model shown in figure 365 is a special, waterproofed unit for use

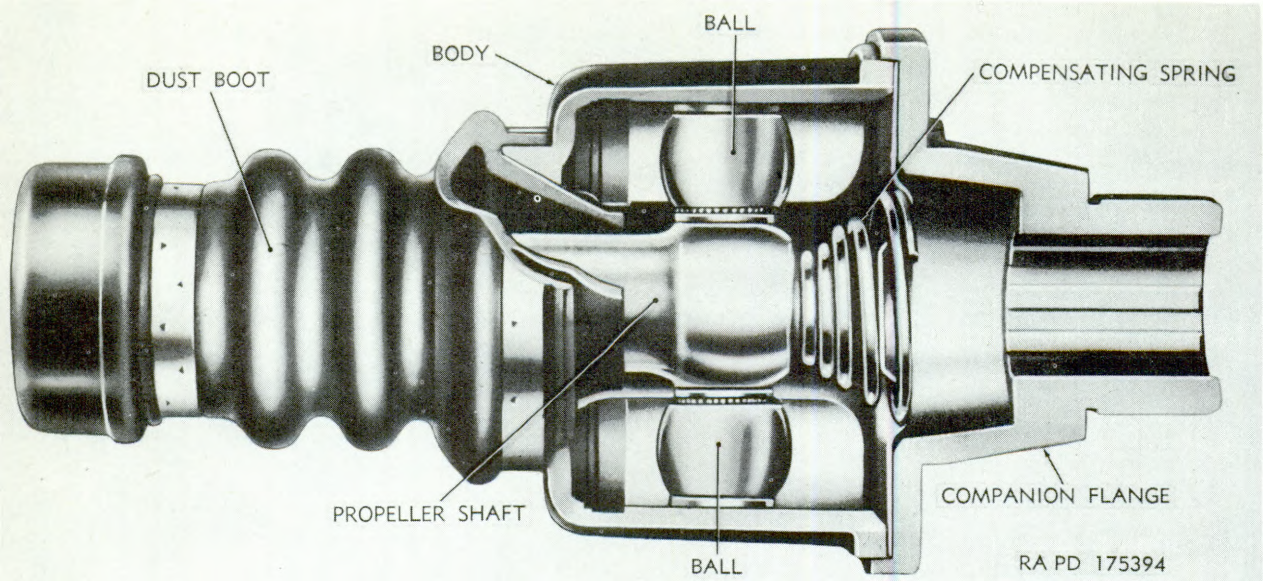


Figure 363. Universal joint of the ball-and-trunnion type—partially cutaway view.

in amphibious cargo carriers where it will be submerged in water. Note the manner in which a rubber O-ring is used to improve the seal of the dust boot to the body.

216. Constant-Velocity Universal Joints

a. General.

(1) The speed fluctuations caused by the conventional universal joints described in paragraph 215*b*(1), do not cause much difficulty in automotive propeller shafts where they have to drive through small angles only. In front-wheel drives where the wheels are cramped up to 30° in steering, velocity fluctuations present a serious problem. Conventional universal joints would cause hard steering, slippage, and tire wear each time the vehicle turned the corner. Constant-velocity universal joints, which eliminate the pulsations, are used exclusively today to connect the front axle shaft to the driving wheels.

(2) The conventional universal joint produces velocity fluctuations because the journal connecting the two yokes does not allow free movement other than a pivoting action. Velocity fluctuations occur because the journal tilts back and forth (wobbles) as the joint rotates. This tilting movement is translated into rotary movement and, when the journal tilts toward the output shaft, it adds to the speed of the output; and when the journal tilts away from the output shaft, it subtracts from the speed and the output shaft rotates slower than the input shaft. The only time that the speeds of the two shafts are equal is when the journal lies in the plane which bisects the angle between the two shafts. As stated in paragraph 215*b*(1), this occurs only four times during each revolution.

(3) It can be seen that a universal joint transmitting constant velocity must be designed to permit the point of driving contact between the two halves of the coupling to remain in a plane which bisects the angle between the two shafts. If this is accomplished, some arrangements must be made for the points of the driving contact to move laterally as the joint rotates. Keeping this in mind, it will be easier to understand the principles of constant-velocity joints which are in universal use today. Three types used in Army vehicles are: Rzeppa, Bendix-Weiss, and Tracta. These types are discussed separately to show that, in all, a plane passed through the points of the driving engagement will at all times bisect the angle between the driving and the driven shaft.

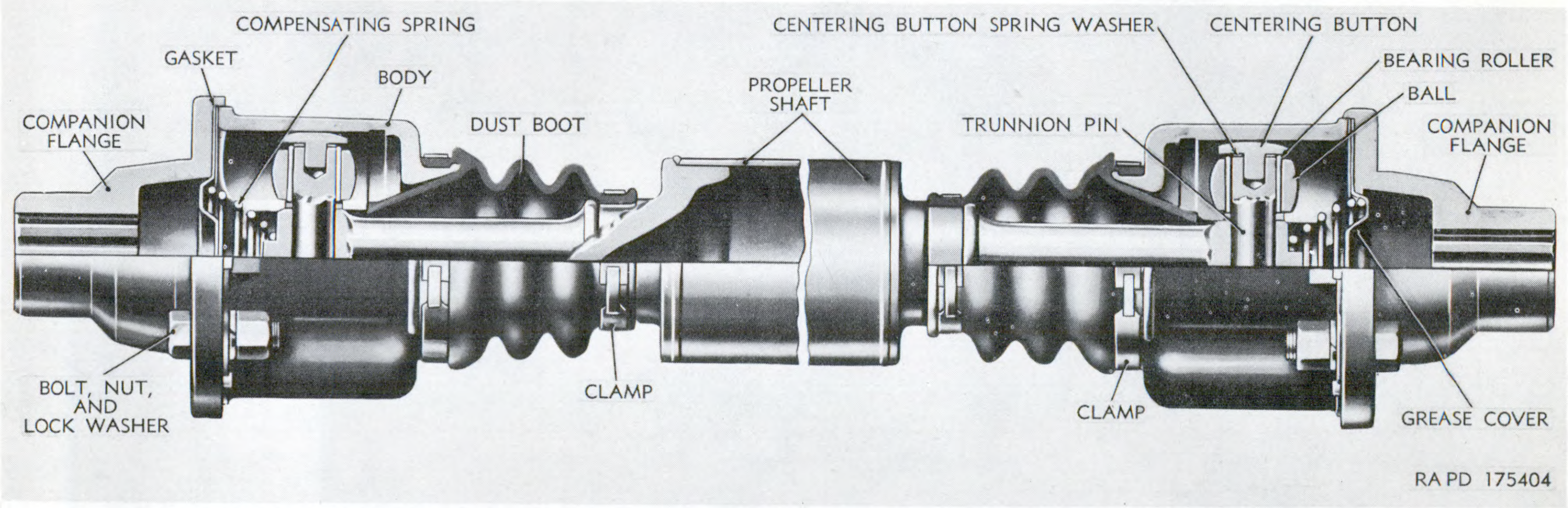

COMPENSATING SPRING
GASKET
BODY
COMPANION FLANGE
DUST BOOT
PROPELLER SHAFT
CENTERING BUTTON SPRING WASHER
CENTERING BUTTON
BEARING ROLLER
BALL
TRUNNION PIN
COMPANION FLANGE
BOLT, NUT, AND LOCK WASHER
CLAMP
CLAMP
GREASE COVER
RA PD 175404

Figure 364. Propeller shaft using ball-and-trunnion universal joints.

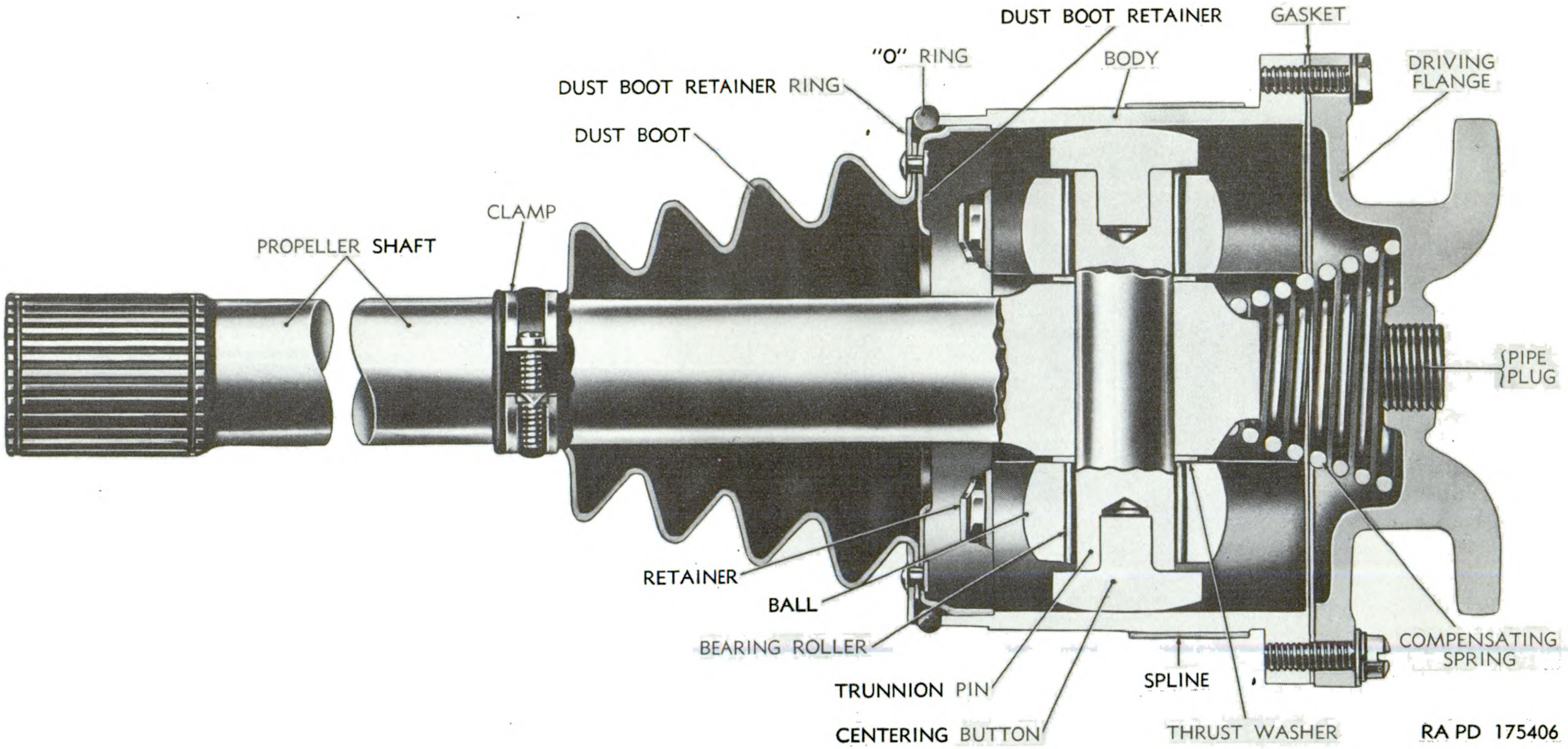

DUST BOOT RETAINER
GASKET
"O" RING
BODY
DRIVING FLANGE
DUST BOOT RETAINER RING
DUST BOOT
CLAMP
PROPELLER SHAFT
PIPE PLUG
RETAINER
BALL
BEARING ROLLER
TRUNNION PIN
CENTERING BUTTON
SPLINE
THRUST WASHER
COMPENSATING SPRING
RA PD 175406

Figure 365. **Special waterproofed ball-and-trunnion universal joint.**

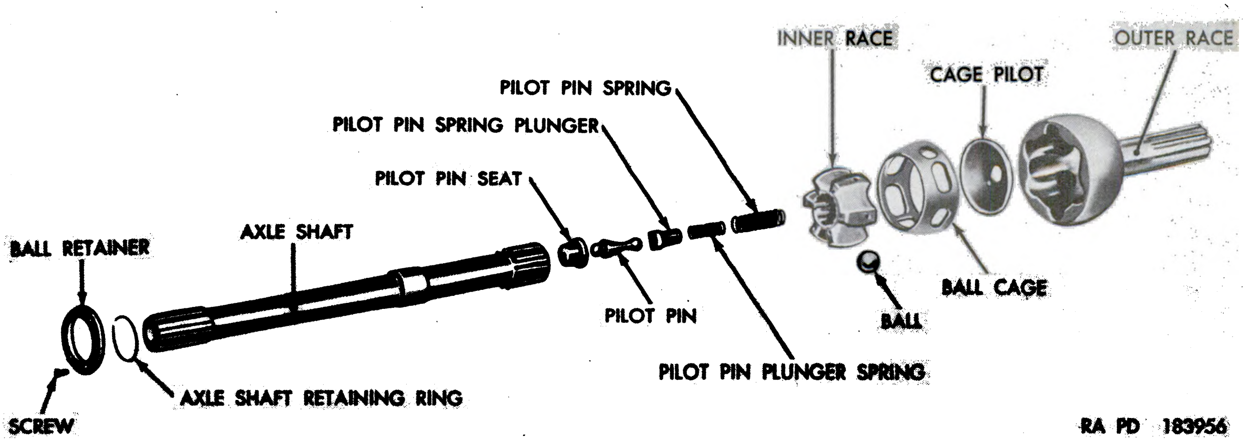

INNER RACE
OUTER RACE
CAGE PILOT
PILOT PIN SPRING
PILOT PIN SPRING PLUNGER
PILOT PIN SEAT
AXLE SHAFT
BALL RETAINER
PILOT PIN
BALL CAGE
BALL
PILOT PIN PLUNGER SPRING
AXLE SHAFT RETAINING RING
SCREW
RA PD 183956

Figure 366. Rzeppa constant velocity universal joint — disassembled view.

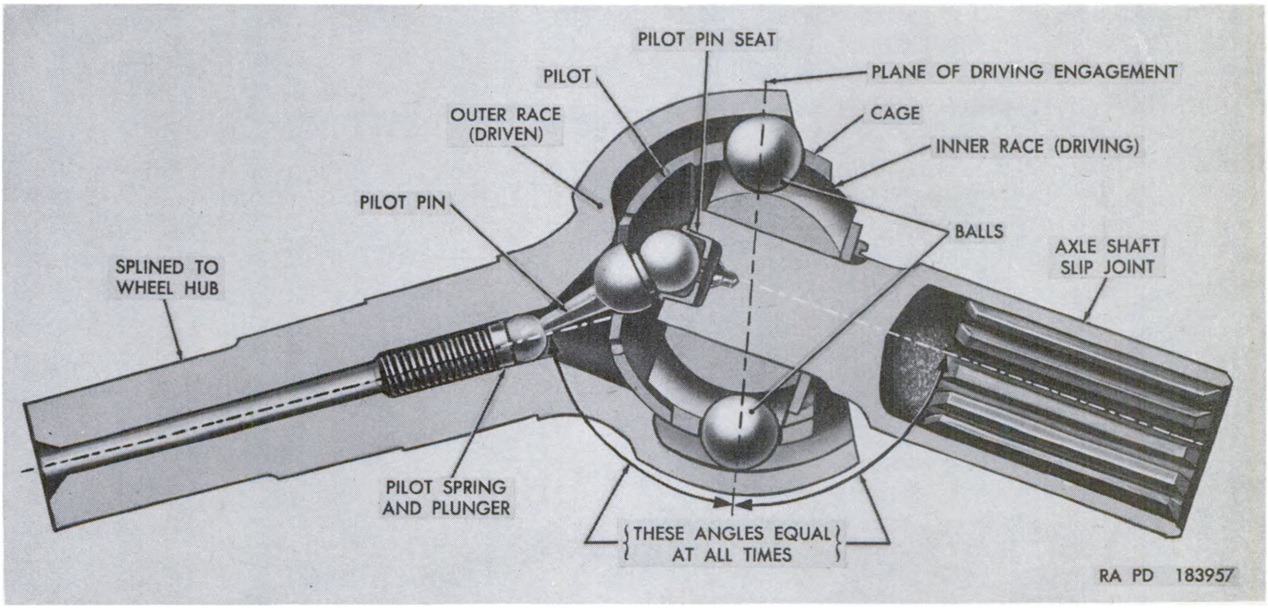

PILOT PIN SEAT
PILOT
PLANE OF DRIVING ENGAGEMENT
OUTER RACE (DRIVEN)
CAGE
INNER RACE (DRIVING)
PILOT PIN
BALLS
AXLE SHAFT SLIP JOINT
SPLINED TO WHEEL HUB
PILOT SPRING AND PLUNGER
THESE ANGLES EQUAL AT ALL TIMES
RA PD 183957

Figure 367. Rzeppa constant velocity universal joint—cross sectional view.

b. Rzeppa Universal Joint.

(1) The Rzeppa joint is a ball bearing type in which the balls furnish the only points of driving contact between the two halves of the coupling. The details of the component parts, adapted for use in a front driving axle, are shown in figure 366. The inner race (driving member) is splined to the inner axle shaft; the outer race (driven member) is a spherical housing which is an integral part of the outer shaft; the ball cage is fitted between the two races. The close spherical fit between the three main members supports the inner shaft whenever it is required to slide in the inner race, relieving the balls of any duty other than the transmission of power.

(2) The movement of the six balls is controlled by the cage. The cage positions the balls in a plane at right angles to the two shafts when the shafts are in the same line. A pilot pin, located in the outer shaft, moves the pilot and the cage by a simple leverage in such a manner that the angular movement of the cage and the balls is one-half the angular movement of the driven shaft. When the driven shaft is moved 20°, the cage and the balls move 10°. As a result, the balls of the constant-velocity universal joint are positioned from the top view, to bisect the angle formed (fig. 367).

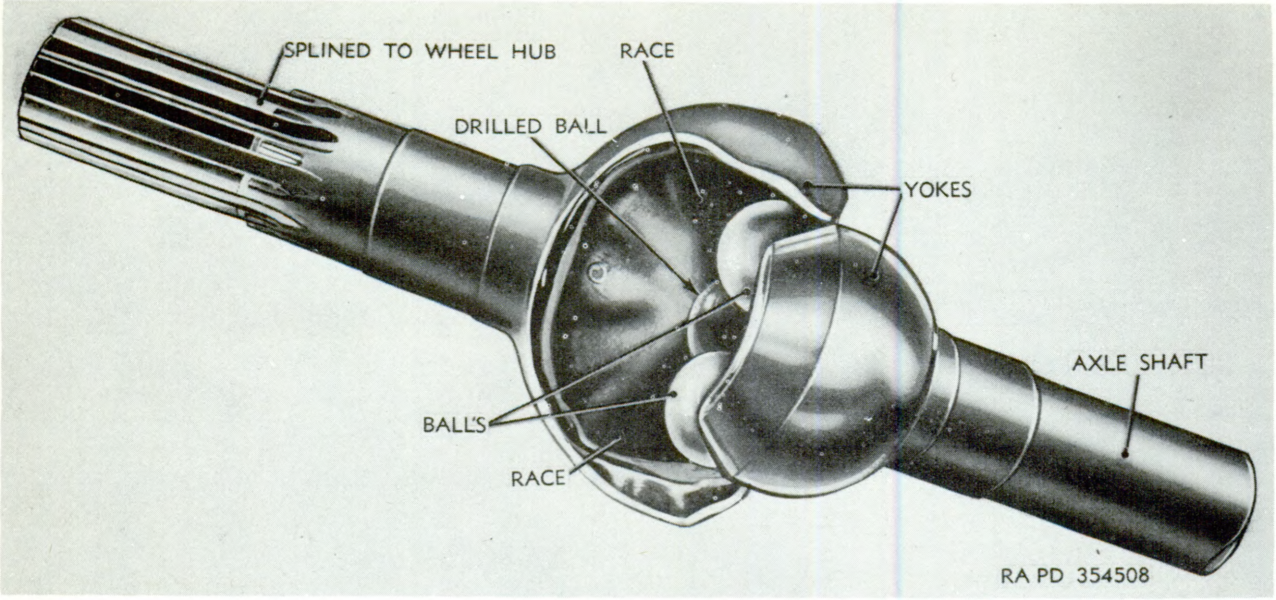

SPLINED TO WHEEL HUB
RACE
DRILLED BALL
YOKES
AXLE SHAFT
BALLS
RACE
RA PD 354508

Figure 368. Bendix-Weiss constant velocity universal joint—assembled view.

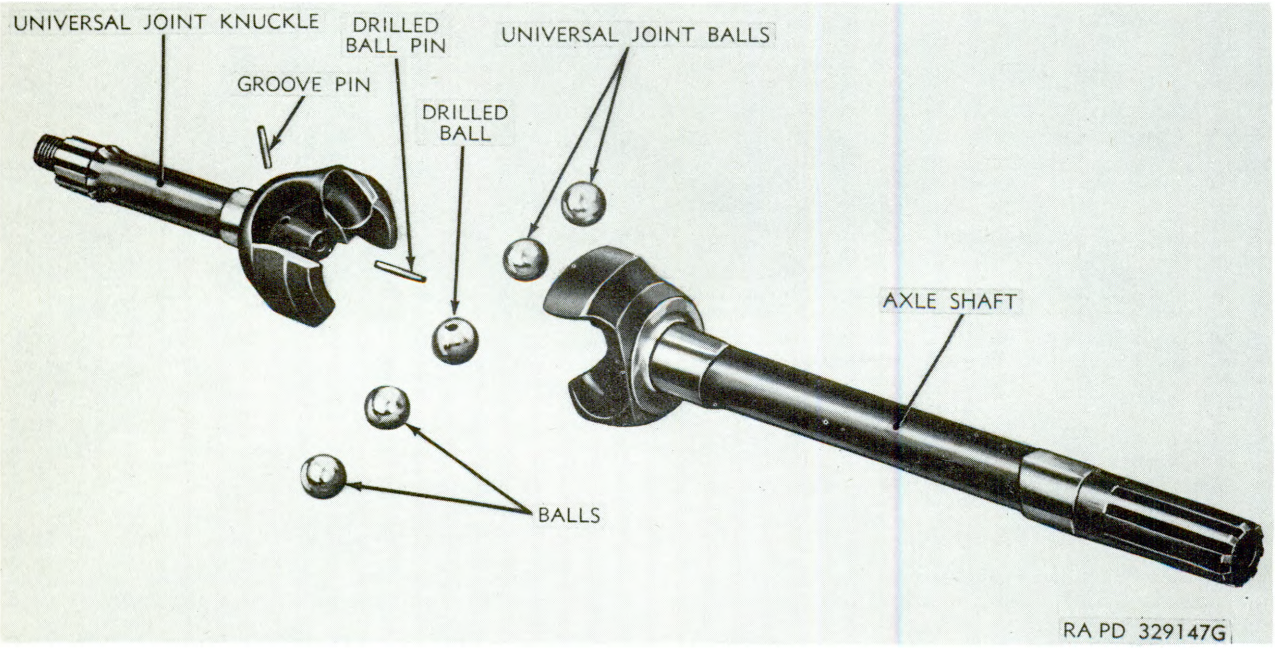
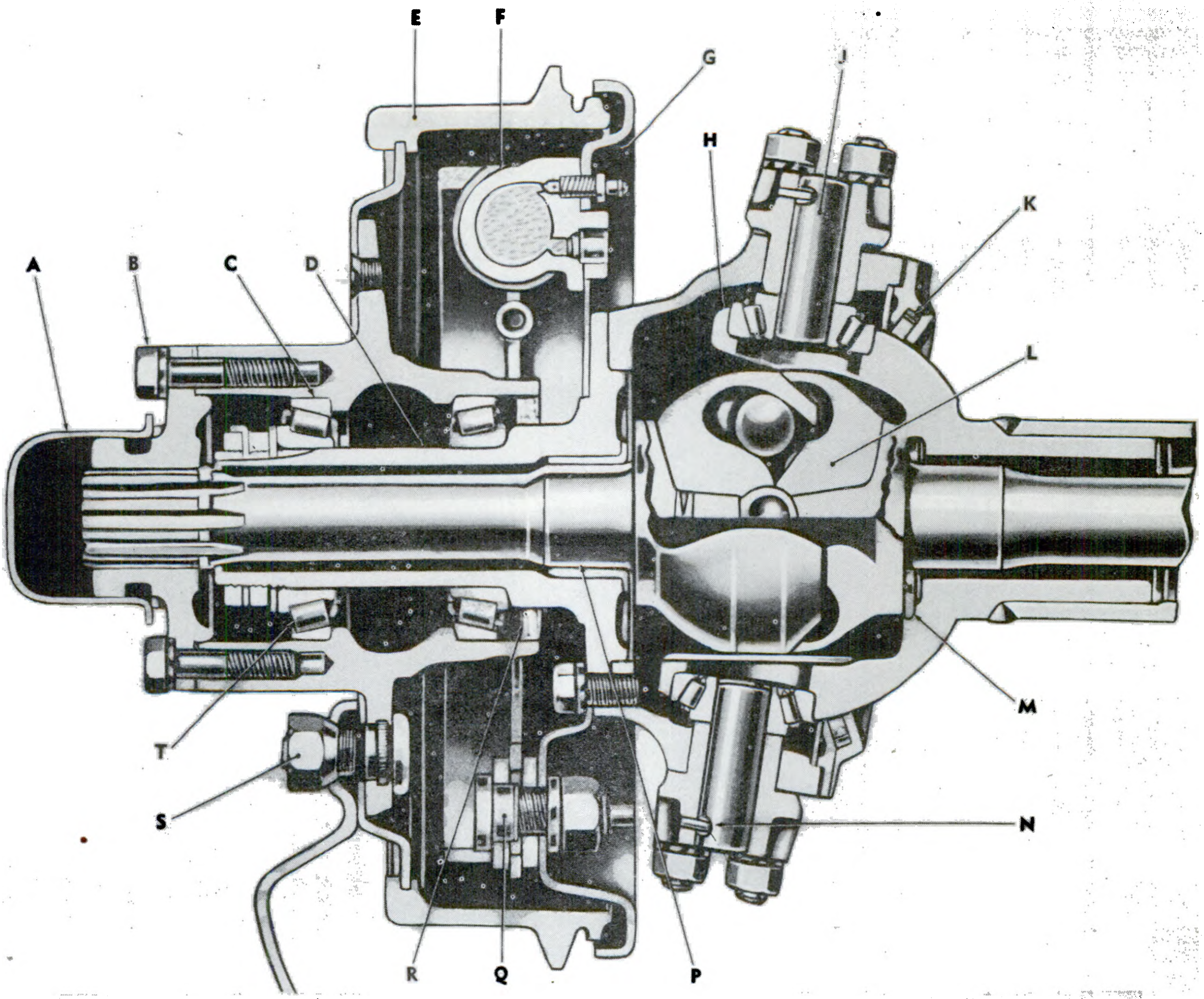

UNIVERSAL JOINT KNUCKLE
DRILLED BALL PIN
UNIVERSAL JOINT BALLS
GROOVE PIN
DRILLED BALL
AXLE SHAFT
BALLS
RA PD 329147G

Figure 369. Bendix-Weiss constant velocity universal joint—disassembled view.

c. *Bendix-Weiss Universal Joint.*

(1) The Bendix-Weiss joint (figs. 368, 369, and 370) also uses balls which furnish points of driving contact, but its construction differs from that of the Rzeppa in that the balls are a tight fit between the two halves of the coupling and no cage is used. The center ball rotates on a pin inserted in the outer race, and serves as a locking medium for the four other balls. The driving contact remains on the plane which bisects the angle between the two shafts, but it is the rolling friction between the four balls and the universal joint housing that positions the balls.

(2) The manner in which this action is accomplished can best be illustrated by placing a ruler across a round pencil on a table; if the ruler is moved to cause the pencil to roll without slipping, the pencil travel is exactly half that of the ruler.



A—HUB CAP
B—DRIVE FLANGE SCREW
C—FRONT WHEEL BEARING CUP
D—WHEEL BEARING SPINDLE
E—BRAKE DRUM
F—WHEEL BRAKE CYLINDER
G—BRAKE LOCKING PLATE
H—KING PIN BEARING CUP
J—KING PIN
K—OIL SEAL
L—BENDIX-WEISS UNIVERSAL JOINT
M—WHEEL SPINDLE BEARING THRUST WASHER
N—KING PIN LOCK PIN
P—WHEEL BEARING SPINDLE BEARING
Q—BRAKE SHOE ANCHOR PIN
R—HUB OIL SEAL
S—HUB BOLT—NUT
T—FRONT WHEEL BEARING CONE

RA PD 183958

Figure 370. Bendix-Weiss universal joint installed on vehicle.

In this example there are three objects: the table top, the pencil, and the ruler; two of which are movable members, and the third stationary. The inner race can be considered as the stationary table top, the ball as the pencil, and the driven race as the ruler. The same relative motion between the pencil and the ruler occurs between the outer (driven) race and the balls in the constant-velocity joint because the balls fit tight enough in the coupling to prevent slippage. The only difference is that motion of the pencil was limited to rolling in a direction perpendicular to the long axis of the pencil, whereas the balls may move in any direction. When both shafts of the constant-velocity joint are in line, that is, at an angle of 180° the balls lie in a plane which is at 90° to the shafts. If it is assumed that the driving shaft remains in the original position, any movement of the driven shaft out of this line will cause the balls to move one-half the angular distance. Therefore, if the driven shaft moves through an angle of

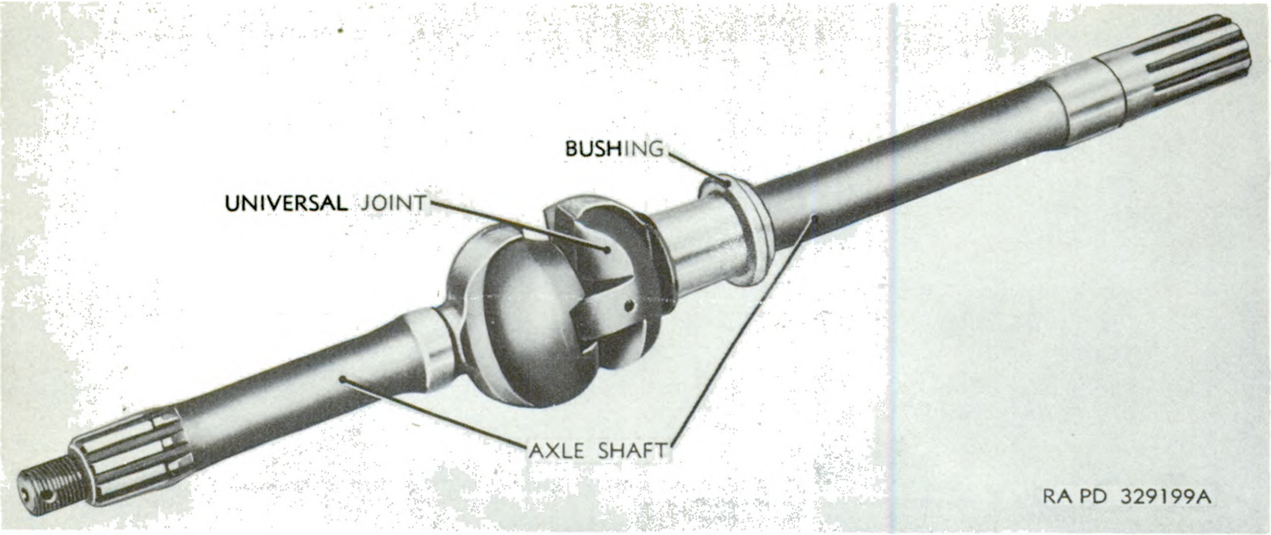

BUSHING
UNIVERSAL JOINT
AXLE SHAFT
RA PD 329199A

Figure 371. Tracta constant-velocity universal joint—assembled view.

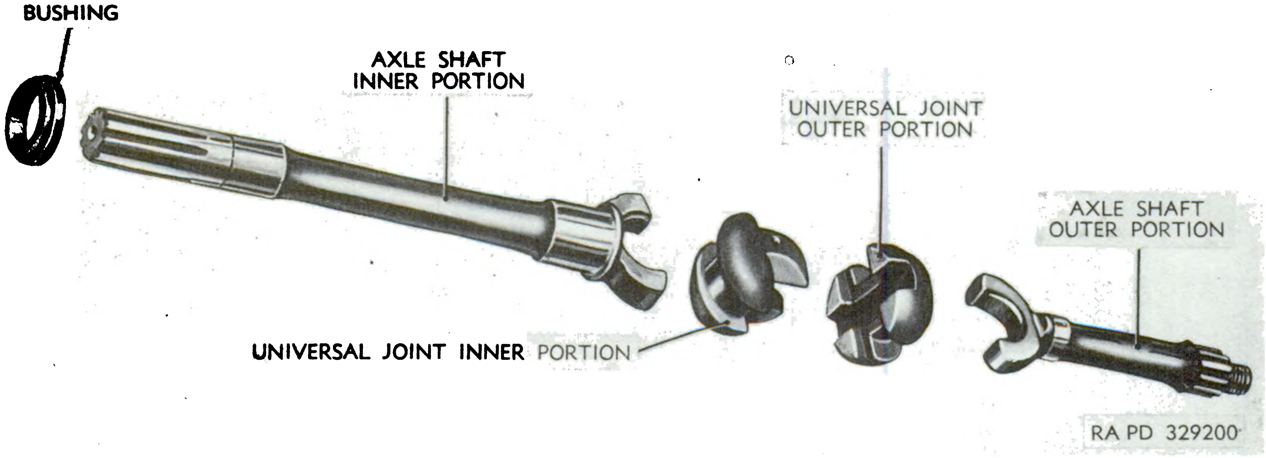

BUSHING
AXLE SHAFT INNER PORTION
UNIVERSAL JOINT OUTER PORTION
AXLE SHAFT OUTER PORTION
UNIVERSAL JOINT INNER PORTION
RA PD 329200

Figure 372. Tracta constant-velocity universal joint—disassembled view.

20°, the angle between the shafts will be reduced to 160°, the balls will move 10° in the same direction, and the angle between the driving shaft and the plane in which the balls lie will be reduced to 80° fulfilling the requirement that the balls must lie in the plane which bisects the angle of drive.

d. Tracta Universal Joint.

(1) The Tracta universal joint (figs. 371 and 372) is the simplest to install and service. It is, in effect, one universal joint within another, with points of driving contact on the outer portions of the joint. This universal joint consists of four main parts: a forked driving shaft, a forked driven shaft, a female (or slotted) joint, and a male (or spigot) joint.

(2) The complete inner joint, consisting of the female joint and the male joint, floats between the forks; movement between the individual halves of the inner joint is permitted in a direction perpendicular to that permitted by the slotted forks, by the action of the spigot moving in the slot. With this arrangement, the points of driving contact are allowed to move as the universal joint rotates, thereby remaining in a plane which bisects the angle between the two shafts. The fork ends subtend an angle greater than 180° so as to be self-locking once the joint is assembled to the inner parts of the joint. A flat surface is milled on the cylindrical section of the joint to permit the joint to be inserted in place.

CHAPTER 17

DIFFERENTIALS, FINAL DRIVES, AND DRIVING AXLES

Section I. DIFFERENTIALS

217. General

The purpose of differentials, as explained briefly in chapter 13, is to provide for differences in speed of rotation of wheels as a vehicle rounds a corner or travels over uneven ground, or to enable the operator of a tracked vehicle to turn the vehicle by changing the relative speed of the tracks. Details of the mechanisms are explained in this section.

218. Conventional Differential

The bevel drive pinion rotates the bevel drive gear and the differential case to which the final drive gear is riveted. The axle shafts are splined to the differential side gears. Were it not for the differential pinions, each wheel, with its respective axle shaft and side gear, would rotate freely with respect to the differential case and bevel drive gear. Figure 373 shows, in phantom, two views of a conventional differential.

a. Straightahead. When both wheels are rotating at the same speed, as they do on a smooth, straight road, the differential pinions do not rotate about their own axis but serve only to lock all the parts, making them rotate as a unit when the drive differential ring gear is turned by the differential drive pinion.

b. Turns. When the wheels rotate at different speeds, as they do when making a turn, the slowing down of the inner wheel decreases the rotation of its axle shaft and differential side gear with respect to the differential drive ring gear and the differential case. The case forces the differential pinions to rotate along the inner differential side gear, advancing the opposite side gear an equivalent amount with respect to the differential case. The outer wheel thus turns at a higher speed than the inner wheel. If the differential drive ring gear makes four revolutions while the inner wheel is making one, the outer wheel will rotate seven times.

c. Overcoming Loss of Traction. A fault in the conventional differential is that if one driving wheel loses traction and spins, the other wheel which has more traction remains stationary and does not drive the vehicle. In order to overcome this, several devices have been employed from time to time. One device is the hand-controlled differential lock. This is simply a dog clutch, controlled by a hand lever, which clutches one axle shaft fast to the differential case and differential drive ring gear. This forms a rigid connection between the two axle shafts and makes both wheels rotate at the same speed as the differential drive ring gear while the differential lock is engaged. This device is used very seldom, probably because a driver often forgets to disengage the differential lock before the differential action is again required. Automatic devices for doing almost the same thing have been designed. One of these, which is rather extensively used today, is the high-traction differential. It consists of a set of differential pinions and side gears which have fewer teeth and a different tooth form from the conventional gears. Figure 374 shows a comparison between these and standard gears. These differential pinions and side gears depend on a variable radius from the center of the differential pinion to the point where it comes in contact with the side gear teeth, which is, in effect, a variable lever arm. As long as there is relative motion between the pinions and side gears, the torque is unevenly divided between the two driving shafts and wheels; whereas, with the usual differential, the torque is evenly divided at all times. With the high-traction differential, the torque becomes greater on one wheel and less on the other as the pinions move around, until both wheels start to rotate at the same speed. When this occurs, the relative motion between the pinion and side gears stops and the torque on each wheel is again equal. This device assists considerably in starting the vehicle or keeping it rolling in cases where one wheel encounters a slippery spot and loses traction while the other wheel is on a firm spot and has traction. It will not work, however,

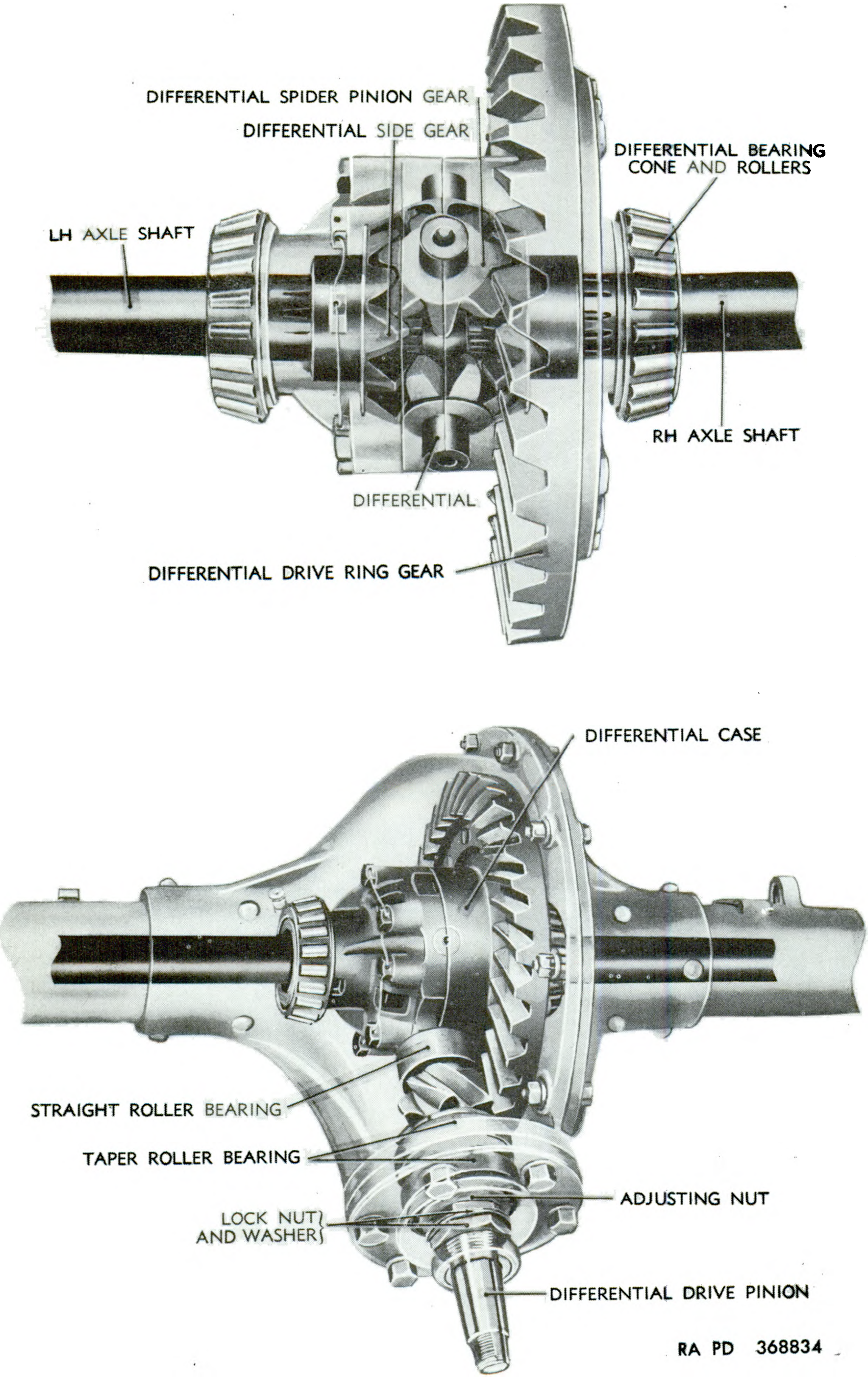
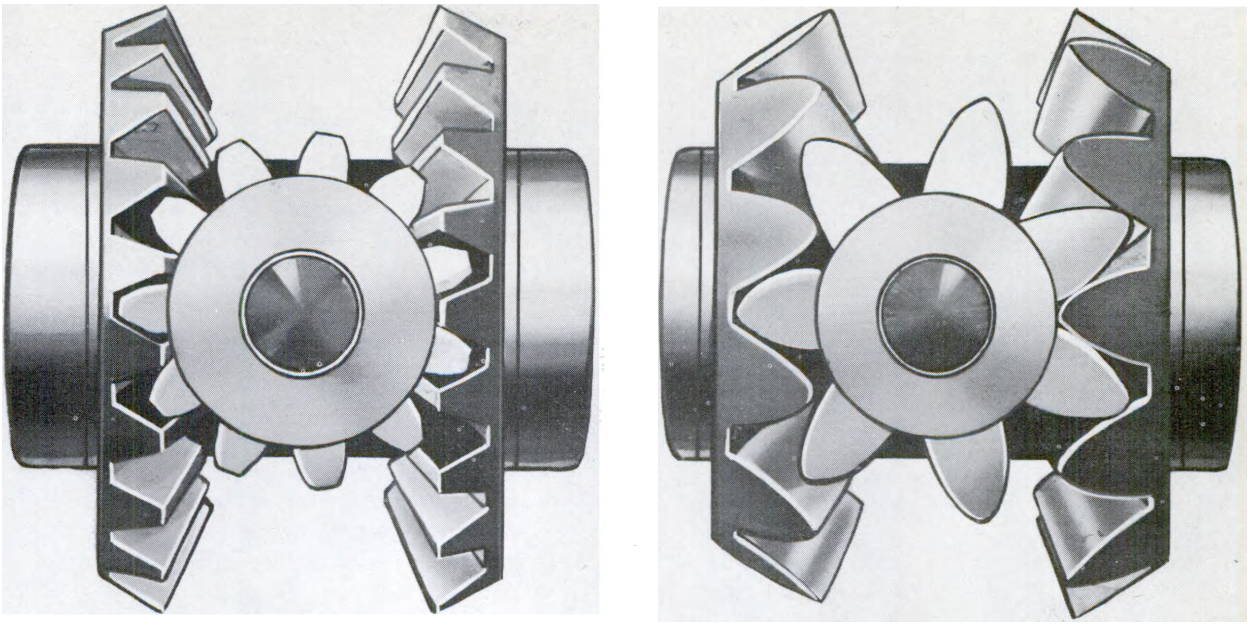

DIFFERENTIAL SPIDER PINION GEAR
DIFFERENTIAL SIDE GEAR
DIFFERENTIAL BEARING CONE AND ROLLERS
LH AXLE SHAFT
RH AXLE SHAFT
DIFFERENTIAL
DIFFERENTIAL DRIVE RING GEAR
DIFFERENTIAL CASE
STRAIGHT ROLLER BEARING
TAPER ROLLER BEARING
ADJUSTING NUT
LOCK NUT AND WASHER
DIFFERENTIAL DRIVE PINION
RA PD 368834

Figure 373. Conventional differential.



CONVENTIONAL DIFFERENTIAL PINION AND SIDE GEARS

HIGH TRACTION DIFFERENTIAL PINION AND SIDE GEARS

RA PD 354509

Figure 374. Comparison of high-traction differential gears and standard differential gears.

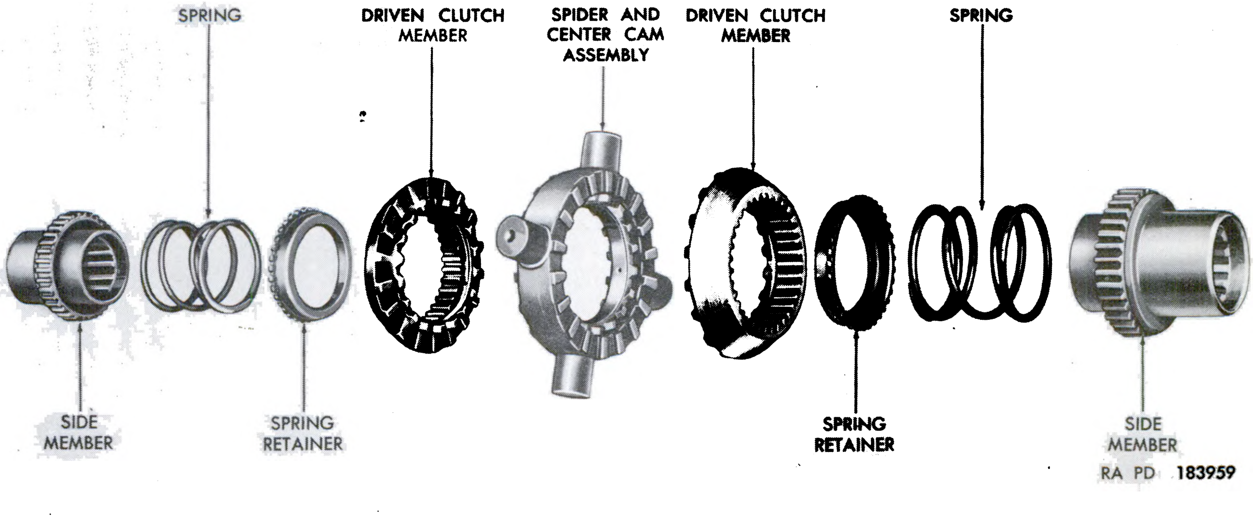

SPRING
DRIVEN CLUTCH MEMBER
SPIDER AND CENTER CAM ASSEMBLY
DRIVEN CLUTCH MEMBER
SPRING
SIDE MEMBER
SPRING RETAINER
SPRING RETAINER
SIDE MEMBER
RA PD 183959

Figure 375. No-spin differential—disassembled view.

when one wheel loses traction completely. In this respect it is inferior to the differential lock.

219. No-Spin Differential

a. General. To provide a means of improving tractive effort at the driving wheels when one wheel tends to slip from loss of traction, it is necessary that the differential prevent actual slippage and supply torque to the driving wheels only to the extent that the wheels can utilize the torque without slipping. The No-spin differential utilizes a pair of toothed clutches to do this.

b. Construction. The No-spin differential (fig. 375) does not contain pinion gears and side gears as does the conventional differential. Instead, it consists essentially of a spider attached to the differential drive ring gear through four trunnions, plus two driven clutch members with side teeth that are indexed by spring pressure with side teeth in the spider. Two side members are splined to

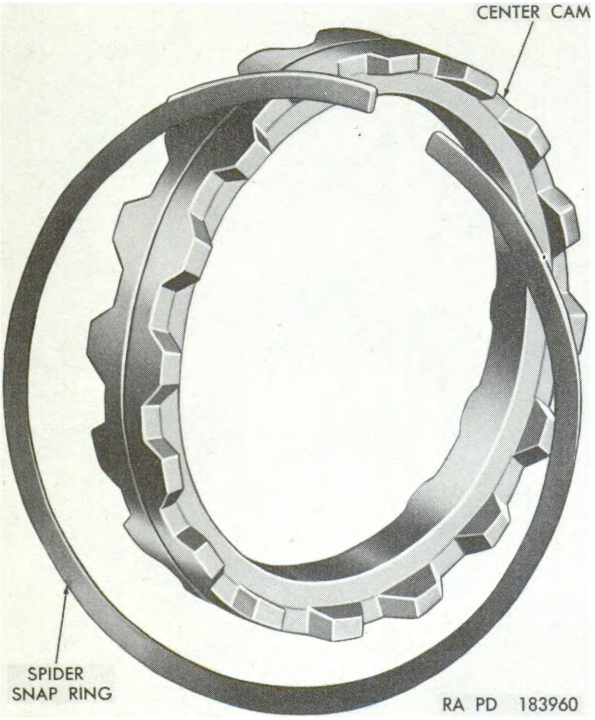

CENTER CAM
SPIDER SNAP RING
RA PD 183960

Figure 376. Construction of center cam.

the wheel axles and in turn are splined into the driven clutch members.

c. Operation in Turning. The center cam (fig. 376) in the spider is held in place by a snap ring that permits the center cam to rotate but does not permit it to move laterally. When making a right turn, the right driven clutch member remains fully engaged with the spider clutch teeth (fig. 377). The spider clutch teeth (the driving teeth) drive the right (inside) wheel at differential drive ring gear speed. The left wheel (outside) covers a greater distance and must turn faster than differential drive ring gear speed. The differential must permit this action since, as the left wheel begins to turn faster, the left driven clutch member also turns faster than differential drive ring gear and spider speed. As the left-driven clutch member begins to turn faster, the cam lobes or ramps on its edge ride up on the cam lobes on the center cam. This action pushes the left-driven clutch member away from the spider so the clutch teeth disengage. This action is shown in figure 378. As the crest of the ramp is passed, spring pressure forces the teeth of the driven clutch member back into full engagement with the teeth on the spider. But the action is repeated as long as the left wheel turns more rapidly than the right wheel. Full drive is applied to the right wheel; no drive is applied to the left wheel. But as soon as the vehicle completes the turn and the left wheel slows down to right-wheel speed, driving power is applied equally to both. For a left turn, the action is similar except that full drive is applied to the left wheel; the right wheel turns more rapidly than the left wheel.

d. Tractive Effort. With this differential, one wheel cannot spin because of loss of tractive effort and thereby deprive the other wheel of driving effort. For example, one wheel is on ice and the other wheel is on dry pavement. The wheel on ice is assumed to have no traction. However, the wheel on dry pavement will pull to the limit of its tractional resistance at the pavement. The wheel on ice cannot spin because wheel speed is governed by the speed of the wheel applying tractive effort.

e. Silent Type of No-Spin Differential (fig. 379). In the silent type of No-spin differential, the construction is very similar to the unit described in *b* above. However, the center cam has wider teeth to carry the two sets of cams in each driven clutch member. One set is fixed, the other is able to rotate in one direction or the other a few degrees with respect to the fixed set. The rotatable or holdout cam ring is slotted, and a key in the

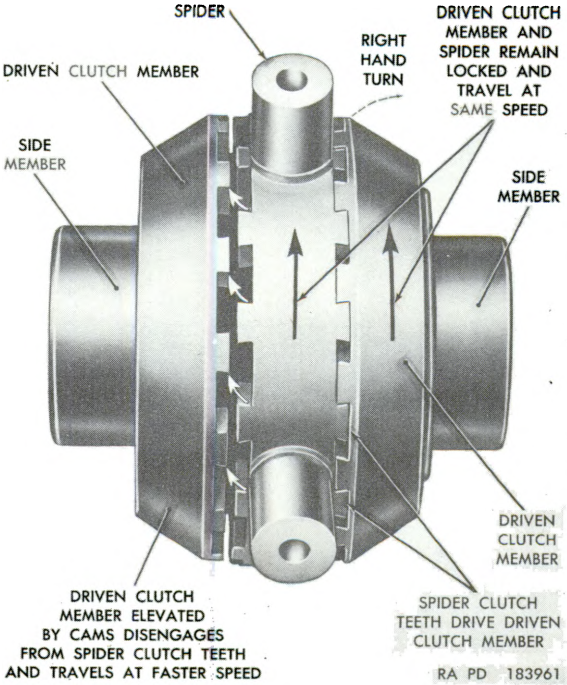

SPIDER
RIGHT HAND TURN
DRIVEN CLUTCH MEMBER AND SPIDER REMAIN LOCKED AND TRAVEL AT SAME SPEED
DRIVEN CLUTCH MEMBER
SIDE MEMBER
SIDE MEMBER
DRIVEN CLUTCH MEMBER
DRIVEN CLUTCH MEMBER ELEVATED BY CAMS DISENGAGES FROM SPIDER CLUTCH TEETH AND TRAVELS AT FASTER SPEED
SPIDER CLUTCH TEETH DRIVE DRIVEN CLUTCH MEMBER
RA PD 183961

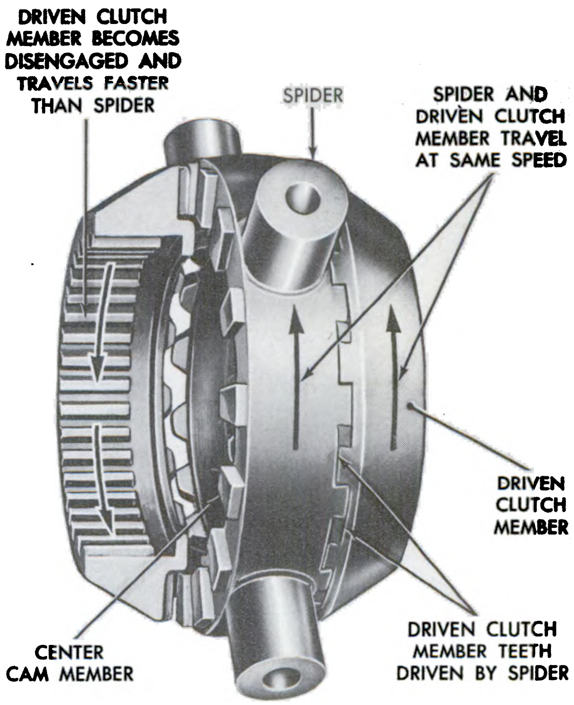
Figure 377. Operation of No-spin differential during a turn.

spider fits this slot to limit the independent rotation of the cam. The key also limits the rotation of the center cam. In operation, when one wheel is turning faster than the other (as in rounding a turn), the faster-turning splined side member and driven clutch member causes the ramps on the center cam and driven clutch member cam to push the driven clutch member away from the spider. This action is similar to that described in *c* above for the other No-spin differential. The teeth are separated so no driving can take place. In this unit, however, the teeth do not repeatedly index because the rotatable cam, left slightly behind, prevents this. The ramps on the rotatable cam are half-way between the ramps on the fixed cam of the driven clutch member. The staggered ramps will not permit teeth engagement. As soon as the turn is completed, the driven clutch member slows down to spider speed, the ramps realine, and teeth engagement takes place.

f. Multiple-Axle Installation. Where a vehicle has a tandem driving axle unit or multiple axles, a No-spin differential may be placed in the transfer case between the output shafts to the driving axles. The differential prevents loss of tractive effort from slippage or tractive loss of one set of wheels. Also, it tends to balance torque and prevents interaxle trapped torque which reduces total tractive effort.

220. Controlled Differential

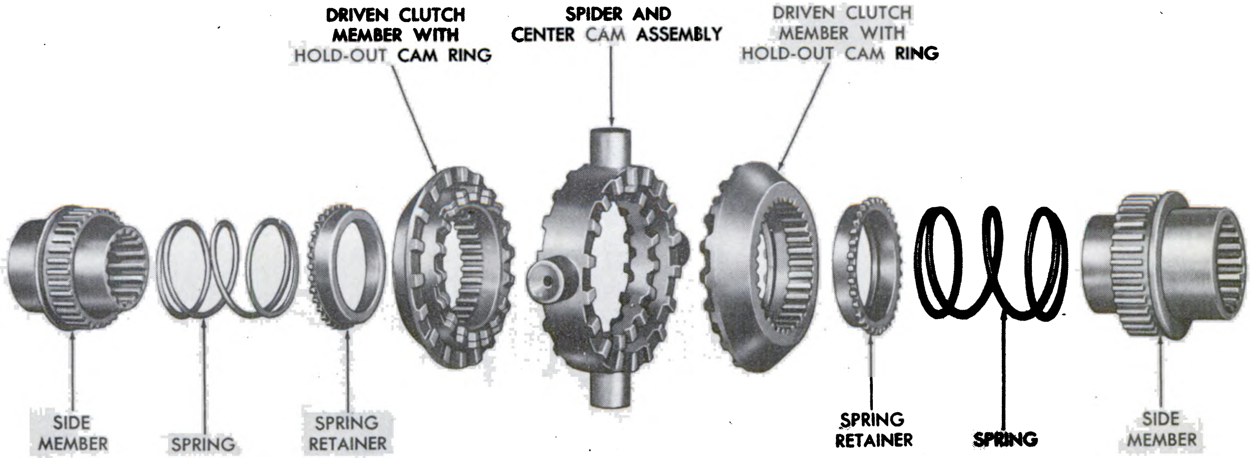
a. Construction. (Figs. 287, 288, and 380). The controlled differential, is in reality, two different assemblies having left and right units joined by the differential carrier. Each side consists of a brakedrum, a sun gear, three external pinions, three internal pinions, and one compensating gear.


DRIVEN CLUTCH MEMBER BECOMES DISENGAGED AND TRAVELS FASTER THAN SPIDER
SPIDER
SPIDER AND DRIVEN CLUTCH MEMBER TRAVEL AT SAME SPEED
DRIVEN CLUTCH MEMBER
CENTER CAM MEMBER
DRIVEN CLUTCH MEMBER TEETH DRIVEN BY SPIDER

CENTER CAMS SERVE AS RAMPS TO ELEVATE THE DRIVEN CLUTCH MEMBERS THROUGH CONTACT WITH THEIR FIXED CAMS

RA PD 183962

Figure 378. Action of center cam during a turn.


DRIVEN CLUTCH MEMBER WITH HOLD-OUT CAM RING
SPIDER AND CENTER CAM ASSEMBLY
DRIVEN CLUTCH MEMBER WITH HOLD-OUT CAM RING
SIDE MEMBER
SPRING
SPRING RETAINER
SPRING RETAINER
SPRING
SIDE MEMBER

RA PD 183963

Figure 379. Silent type of No-spin differential—disassembled view.

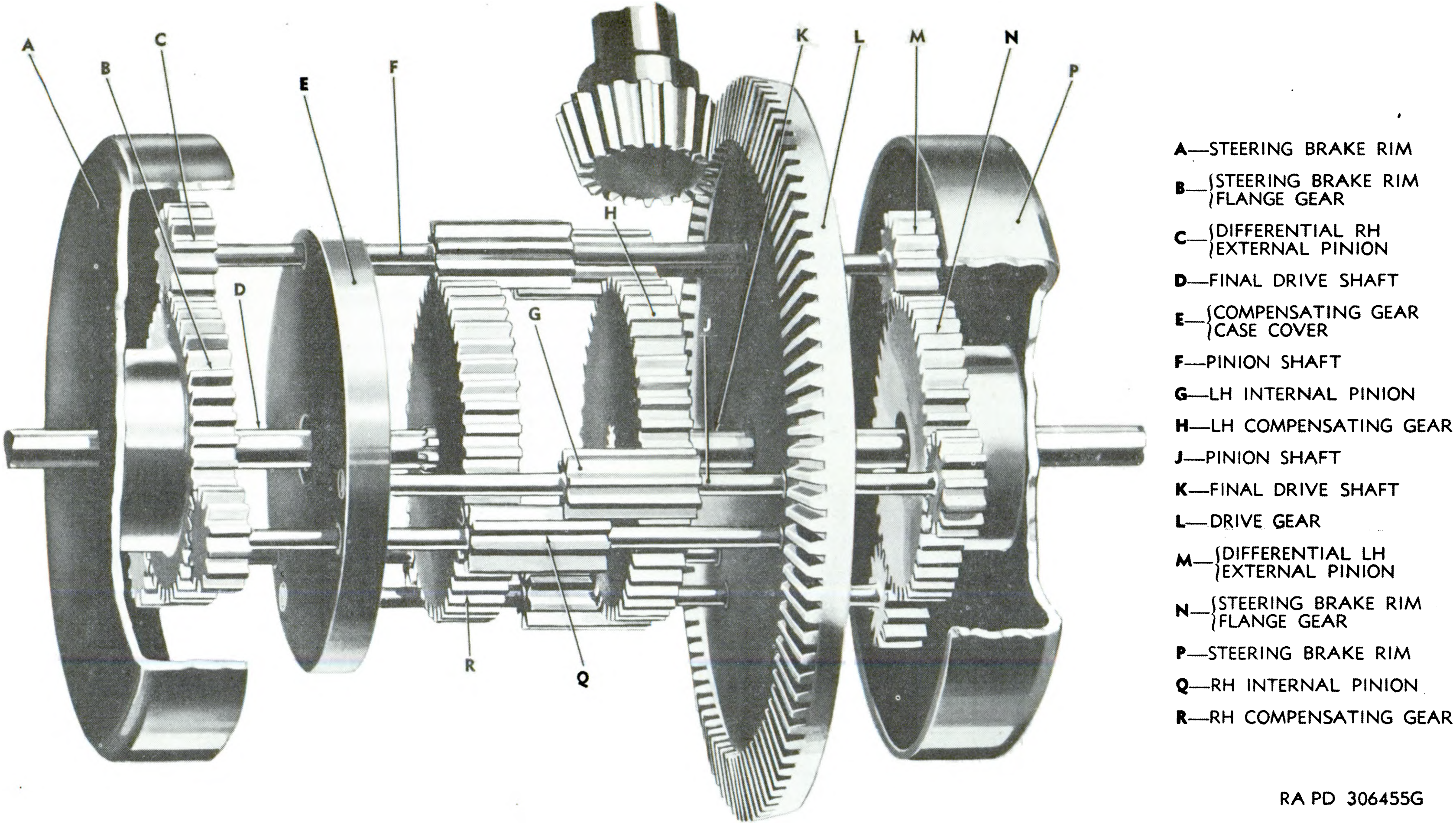
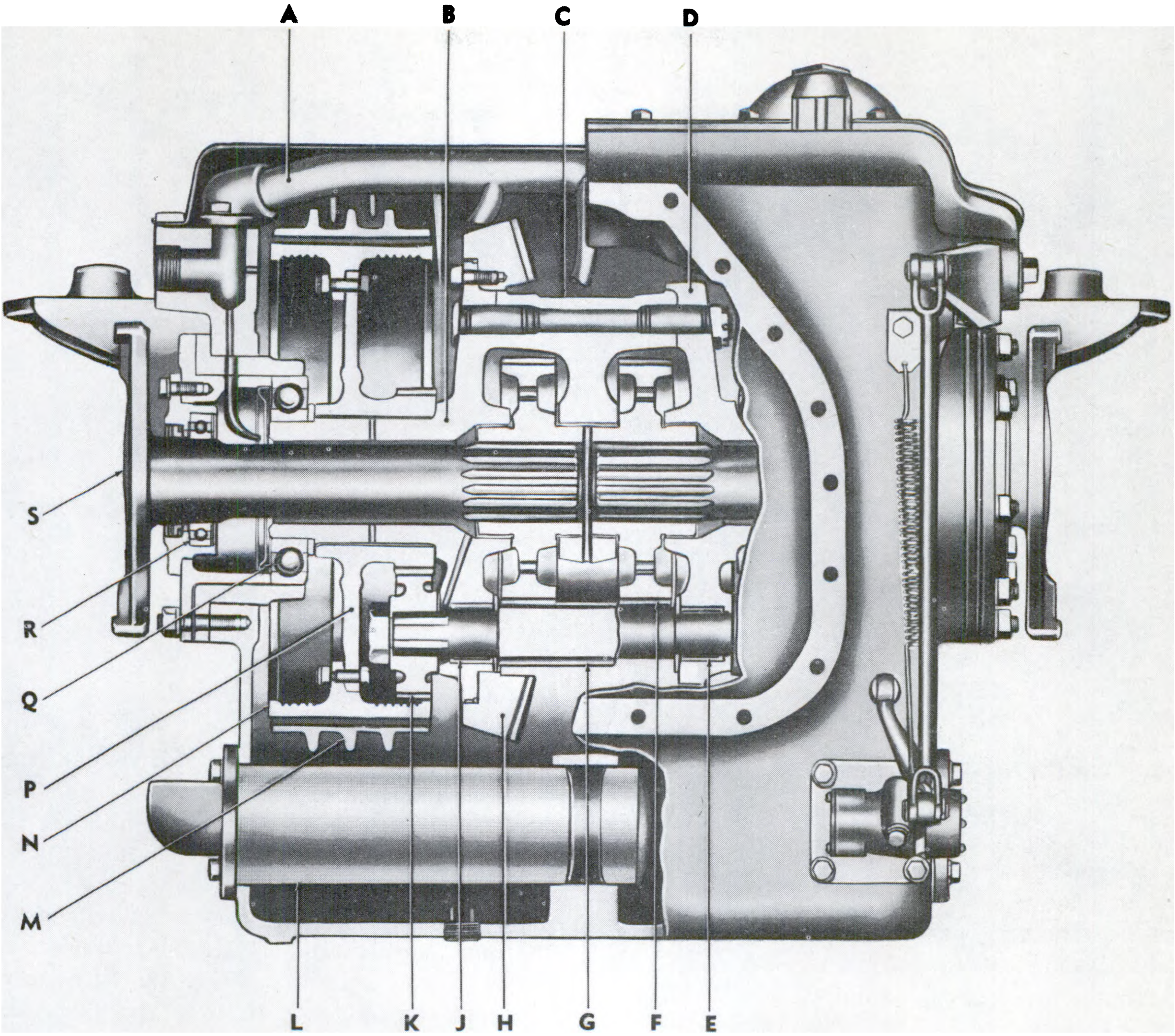

A
B
C
E
F
D
G
H
K
L
M
N
P
J
R
Q
A—STEERING BRAKE RIM
B—{STEERING BRAKE RIM
FLANGE GEAR
C—{DIFFERENTIAL RH
EXTERNAL PINION
D—FINAL DRIVE SHAFT
E—{COMPENSATING GEAR
CASE COVER
F—PINION SHAFT
G—LH INTERNAL PINION
H—LH COMPENSATING GEAR
J—PINION SHAFT
K—FINAL DRIVE SHAFT
L—DRIVE GEAR
M—{DIFFERENTIAL LH
EXTERNAL PINION
N—{STEERING BRAKE RIM
FLANGE GEAR
P—STEERING BRAKE RIM
Q—RH INTERNAL PINION
R—RH COMPENSATING GEAR
RA PD 306455G

Figure 380. Controlled differential—schematic view.



A—OIL MANIFOLD
B—RIGHT COMPENSATING CASE COVER
C—COMPENSATING CASE
D—LEFT COMPENSATING CASE COVER
E—SMALL PINION BEARING
F—DIFFERENTIAL FINAL DRIVE SHAFT GEAR

G—INTERNAL PINION
H—RING GEAR
J—LARGE PINION BEARING
K—EXTERNAL GEAR
L—OIL SCREEN
M—STEERING BRAKE SHOE

N—STEERING BRAKE DRUM
P—STEERING BRAKE DRUM FLANGE
Q—COMPENSATING CASE COVER BEARING
R—FINAL DRIVE SHAFT BEARING
S—DIFFERENTIAL FINAL DRIVE SHAFT

RA PD 183964

Figure 381. Controlled differential—cross sectional view.

b. Operation. Figures 381 and 382 are sectional views of a controlled differential. When the vehicle is moving straight ahead, the entire differential assembly turns as a unit and transmits equal power and speed to each track through the final drive (fig. 383). When the left brake band is applied to the brakedrum, the left compensating gear is retarded and rotates slower than the differential carrier, while the right compensating gear is speeded up and rotates faster than the differential carrier. As each compensating shaft is splined to each compensating gear, the final analysis will result in the left track revolving slower than the right track, causing the vehicle to turn to the left. Exactly the reverse procedure takes place if the right brake is applied.

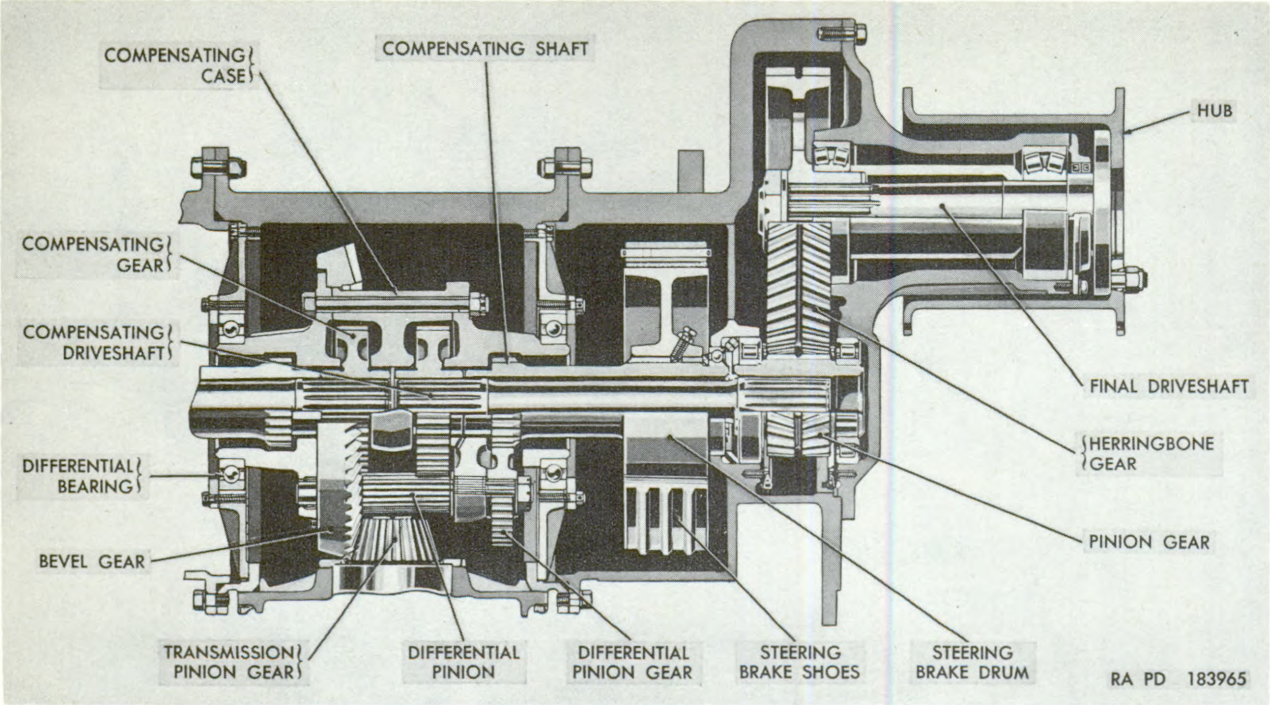

COMPENSATING CASE
COMPENSATING SHAFT
HUB
COMPENSATING GEAR
COMPENSATING DRIVESHAFT
FINAL DRIVESHAFT
HERRINGBONE GEAR
DIFFERENTIAL BEARING
PINION GEAR
BEVEL GEAR
TRANSMISSION PINION GEAR
DIFFERENTIAL PINION
DIFFERENTIAL PINION GEAR
STEERING BRAKE SHOES
STEERING BRAKE DRUM
RA PD 183965

Figure 382. Controlled differential and final drive—cross sectional view.

221. Overrunning Clutches

a. General. Overruning clutches of various kinds are used in automotive vehicles. Starters use one type overrunning clutch (par. 142). The stators in torque converters are mounted on overrunning clutches (par. 198). The sprag units used in transfers (par. 210) are, in effect, a form of overrunning clutch. They permit the front wheels to turn faster than, or overrun, the rear wheels of a vehicle. But they lock up if the rear wheels attempt to turn faster than the front wheels. The No-spin overrunning clutch described herein is similar in action to the sprag units used in transfers (par. 210).

b. Purpose. Assembled, partially disassembled, and disassembled views of the No-spin overrunning clutch are shown in figures 384, 385, and 386. The assembly is mounted in the transfer assembly and has an effect very similar to that which the overrunning sprag unit produces (par. 210). That is, during normal operation when both front and rear wheels turn at the same speed, only the rear wheels drive the vehicle. But if the rear wheels should lose traction and begin to spin, they will tend to turn faster than the front wheels. However, the No-spin overrunning clutch prevents this, since it immediately engages to provide drive to all driving axles. It not only drives the front wheels, but also prevents spinning of the rear wheels. In this respect, it is very similar to the No-spin differential (par. 219). The No-spin differential will not permit one rear wheel to spin and deprive the other rear wheel of driving effort. The No-spin differential and the No-spin overrunning clutch are very similar in construction, except the overrunning clutch is somewhat more complex.

c. Action. The central driving member (fig. 384) is externally splined. All driving power to the vehicle wheels passes through the central driving member to the side members. The side members are internally splined and drive separate output shafts. One output shaft carries drive to the rear wheels, the other output shaft carries drive to the front wheels. No drive is supplied to the front wheels during normal running, but drive is supplied to the front wheels if the rear wheels lose traction and begin to slip.

d. Construction and Operation.

(1) The center cam is held in the center driving member by a snap ring (fig. 386). Both sides of the clutch are the same. Examine one side. The prongs on the holdout ring enter the slots in the center cam. The friction spring is set in an

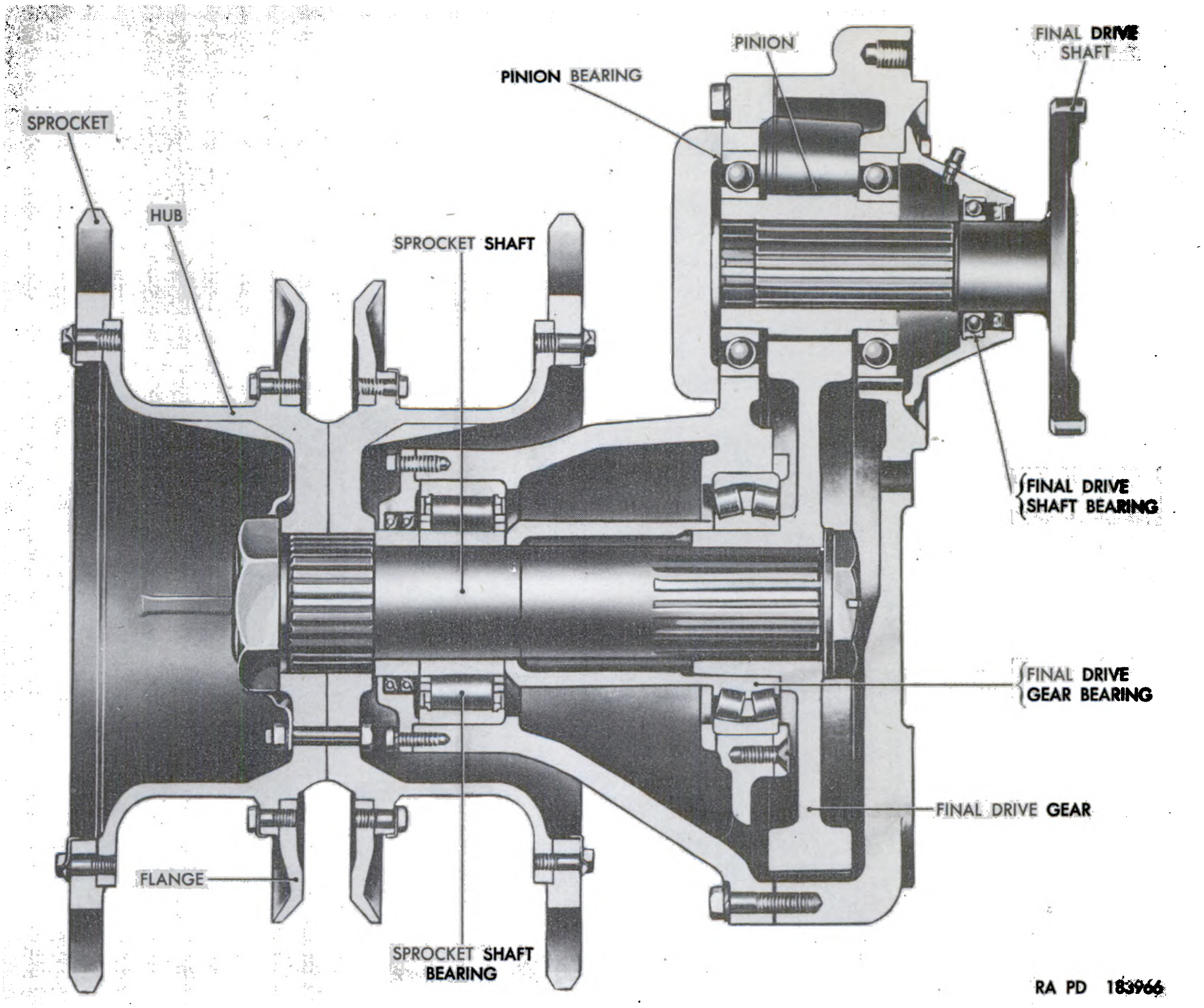

SPROCKET
HUB
SPROCKET SHAFT
PINION BEARING
PINION
FINAL DRIVE SHAFT
FINAL DRIVE SHAFT BEARING
FINAL DRIVE GEAR BEARING
FINAL DRIVE GEAR
FLANGE
SPROCKET SHAFT BEARING
RA PD 183966

Figure 383. Final drive—cross sectional view.

undercut in the teeth on the driven clutch member and it imposes friction on the holdout ring. During normal driving through the clutch, the teeth on the driven clutch member engage the teeth on the central driving member (fig. 384); the driven clutch member is driven through these teeth. The pressure of the heavy coil spring, acting through the spring retainer, maintains the teeth in engagement.

(2) Since the power train usually is geared to drive the front axle at a slightly slower speed than the rear axle, or axles, only the rear wheels drive in normal operation; the front wheels overrun. This gearing difference is in the front-axle and rear-axle differentials. The overrunning clutch permits the front wheels to overrun in the following manner: when the front wheels begin to turn faster than the rear wheels, the front side member of the overrunning clutch turns faster than the remainder of the clutch. As this happens, the inner cams on the driven clutch member (fig. 385) ride up on the cams on the center cam. This action forces the driven clutch member away from the central driving member so that the teeth, through which drive takes place, are disengaged and no drive can take place through the clutch. The teeth continue to pass each other as long as the

side member and driven clutch member turn faster than the central driving member.

(3) The holdout ring is shifted forward by the frictional effect of the friction spring between the ring and driven member. As the ring shifts forward, the notches on the prongs engage the edges of the slots in the center cam. The holdout ring holds the driven clutch member away continuously, so long as the front wheels continue to overrun, preventing repeated reengagement and disengagement of the teeth. However, the instant the rear wheels fail to find full traction and tend to slip, the rear wheels speed up and the central driving member of the clutch speeds up. It therefore catches up with the overrunning front driven clutch member. The slight reversal of torque acting on the holdout ring moves it out of the way so the prongs can drop down into the slots in the center cam. At the same time, the coil spring forces the driven clutch member toward the central driving member so the teeth engage. Drive to

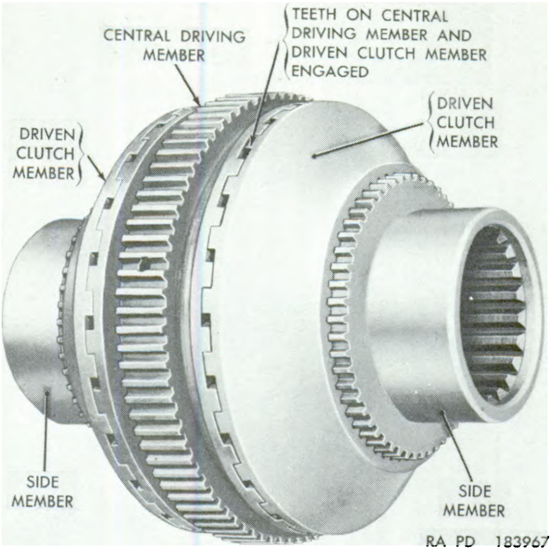

CENTRAL DRIVING MEMBER
TEETH ON CENTRAL DRIVING MEMBER AND DRIVEN CLUTCH MEMBER ENGAGED
DRIVEN CLUTCH MEMBER
DRIVEN CLUTCH MEMBER
SIDE MEMBER
SIDE MEMBER
RA PD 183967

Figure 384. No-spin overrunning clutch.

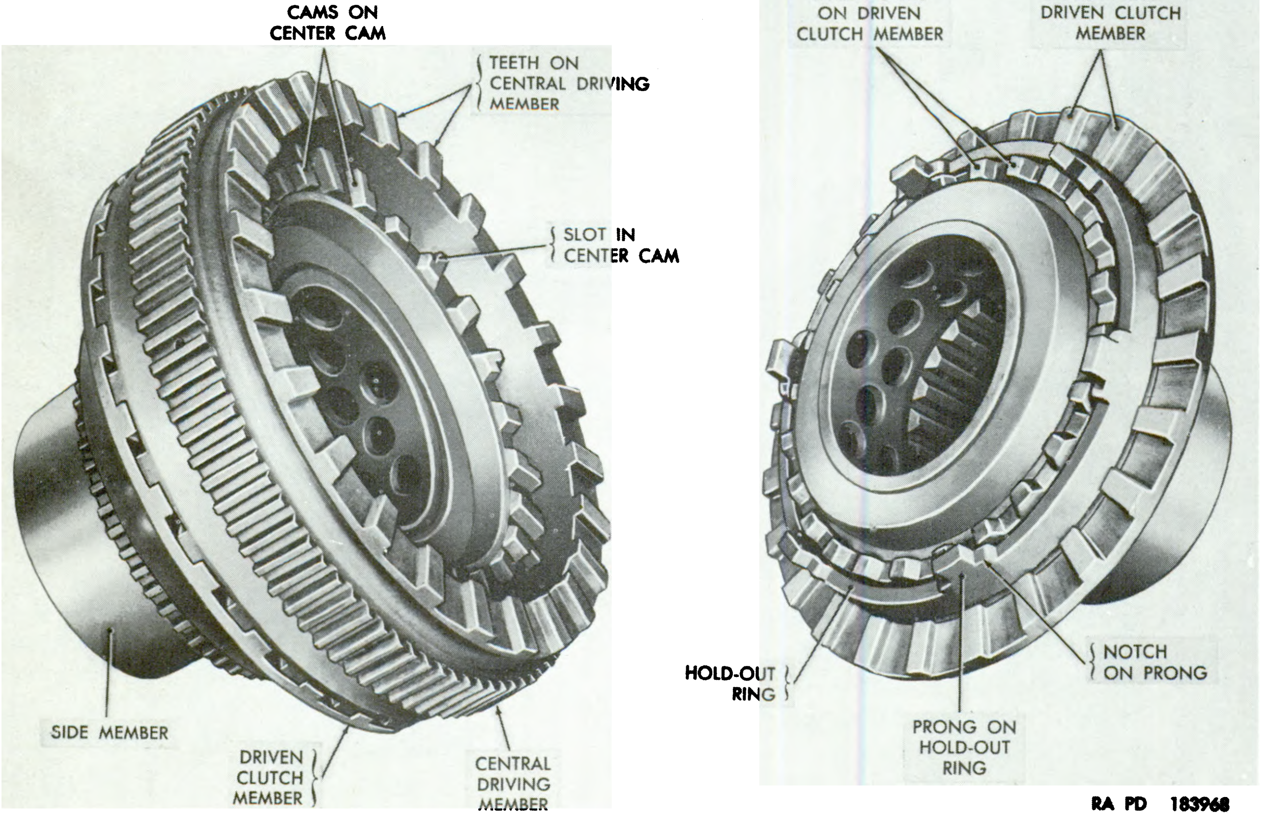

CAMS ON CENTER CAM
TEETH ON CENTRAL DRIVING MEMBER
SLOT IN CENTER CAM
SIDE MEMBER
DRIVEN CLUTCH MEMBER
CENTRAL DRIVING MEMBER
INNER CAMS ON DRIVEN CLUTCH MEMBER
TEETH ON DRIVEN CLUTCH MEMBER
NOTCH ON PRONG
HOLD-OUT RING
PRONG ON HOLD-OUT RING
RA PD 183968

Figure 385. No-spin overrunning clutch—partially disassembled view.

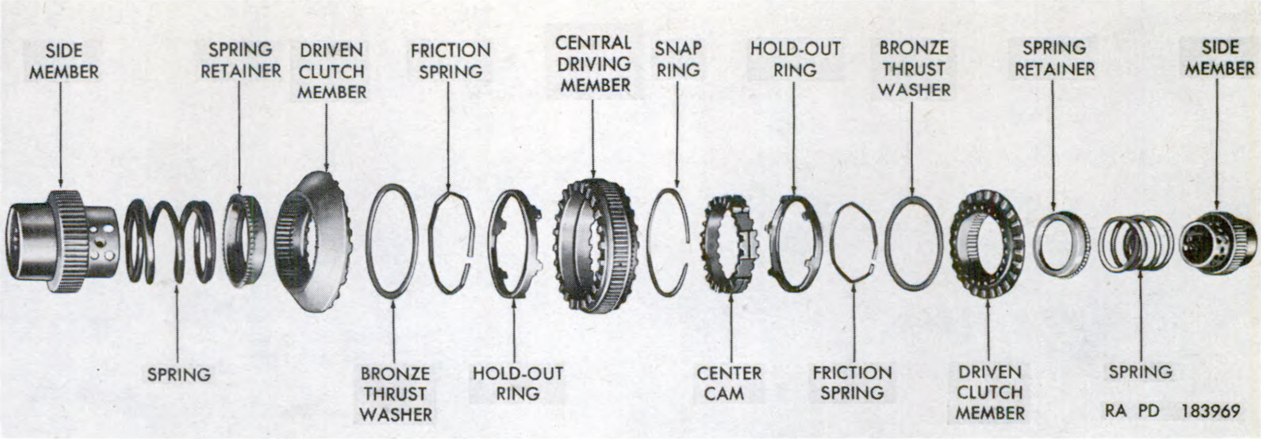


Figure 386. No-spin overrunning clutch—disassembled view.

the front wheels now takes place. However, as soon as the rear wheels find full traction again, they stop spinning and begin to turn slower than the front wheels. The front wheels therefore again overrun as explained in (2) above.

Section II. FINAL DRIVES AND DRIVING AXLES

222. Final Drives (Wheeled Vehicles)

a. A final drive is that part of a power transmission system between the propeller shaft and the differential. Its function is to change the direction of the power transmitted by the propeller shaft through 90° to the driving axles. At the same time, it provides a fixed reduction between the speed of the propeller shaft and the axle driving the wheels. In passenger cars, this speed reduction varies from about 3:1 to 5:1. In trucks, it varies from about 5:1 to 11:1.

b. The gear ratio of the bevel gear final drive is found by dividing the number of teeth on the bevel drive gear by the number of teeth on the pinion. For a worm gear, it is found by dividing the number of teeth on the worm gear by the number of "threads" on the worm. In the case of chain drives, the sprockets are considered gears, and the number of teeth on the driven sprocket is divided by the number of teeth on the driving sprocket.

223. Gear Drives

All the final drives in general use are geared types. The most common of these consists of a pair of bevel gears, that is, a drive pinion connected to the propeller shaft and a bevel drive gear attached to the differential case on the driving axle. These bevel gears may be spur-, spiral-bevel, or hypoid. Spur gears have straight teeth, while spiral-bevel and hypoid gears have curved teeth. Spur gears are little used for this purpose because they are noisy. Spiral-bevel gears are most used. Hypoid gears are used in several passenger cars and in light trucks because they permit the bevel drive pinion to be placed below the center of the bevel drive gear, thereby lowering the propeller shaft to give more body clearance. This gear also operates more quietly. Worm gears are used extensively in trucks because they allow a large speed reduction. These consist of helical worm, similar to screws, and meshing teeth gears. The worms have single, double, triple, or quadruple threads. These type gears are shown in figure 387. Internal gear drives were once popular and are still used in rare instances. They permit a large speed reduction like the double chain drive to which they are similar. A jackshaft is driven by the propeller shaft through bevel gears and differential as it is in the double-chain drive, except that the jackshaft is mounted on the dead rear axle and parallel to it. Spur pinions keyed on the ends of the jackshaft drive internal gears attached to the wheels. The first gear reduction takes place in the bevel pinion and differential drive ring gear and the second in the internal gears.

224. Live Axles

a. A live axle is one that supports part of the weight of a vehicle and also drives the wheels connected to it. The term is applied to the entire

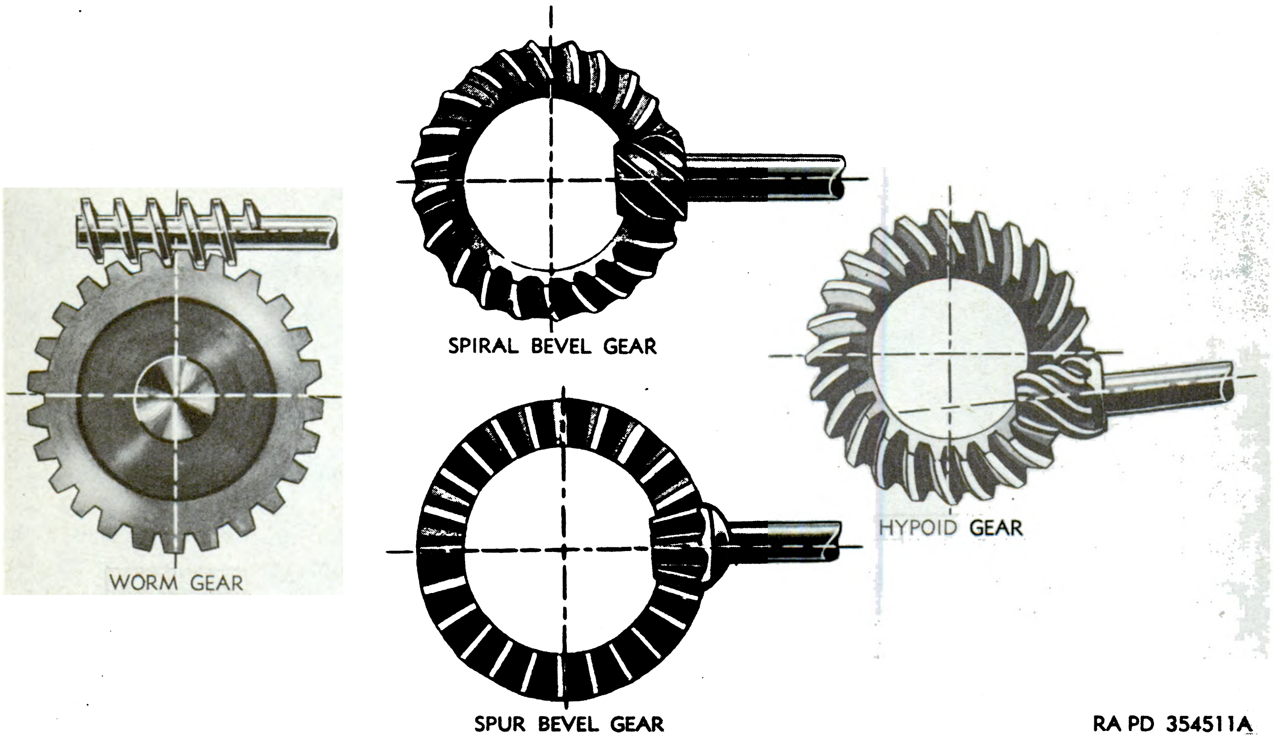


Figure 387. Final drive gears.

assembly, which consists of a housing containing a bevel drive pinion, bevel drive gear differential and axle shafts together with their bearings, and, sometimes additional mechanisms. The term *live axle* is opposed to the term *dead axle*. A dead axle is one that carries part of the weight of a vehicle but does not drive the wheels. The wheels rotate on the ends of the dead axle. The usual front axle of a passenger car is a dead axle and the rear axle is a live axle. In four-wheel drive vehicles, both front and rear axles are live axles, and in six-wheel drive vehicles all three axles are live axles.

b. There are four types of live axles: plain, semifloating, three-quarter floating, and full-floating. These are distinguished by the way in which the axle shafts are connected and the stresses they must carry.

(1) *Plain rear axles.* The plain, or nonfloating, rear axle was one of the first used. In it, the axle shafts are supported in the housing by roller bearings at the center and outer ends. The rear wheels are keyed on tapers at the outer ends of the axle shafts and held by castle nuts and cotter pins. In addition to turning the wheels, the rotating axle shafts carry the entire weight of the rear of the vehicle on their outer ends. All stresses caused by turning corners, skidding, or by wobbling wheels are taken by the axle shafts. The differential side gears are keyed on the inner ends of the axle shafts which carry the weight of the differential case. The stresses created by the operation of the differential are taken by the axle shafts. Side thrust on the axle shafts is taken care of by the roller bearings, and ball bearings are provided at each side of the differential case to take care of end thrust. This type rear axle is now obsolete.

(2) *Semifloating rear axle.* The semifloating rear axle (fig. 388), is used on most passenger and light commercial vehicles. The principal difference between it and the plain live axle is in the manner of supporting the differential assembly. In the plain live axle, the differential case is carried on the inner ends of the axle shafts. In the semi-floating axle, it is carried by bearings mounted in the differential carrier. The axle shafts are splined to the differential side gears.

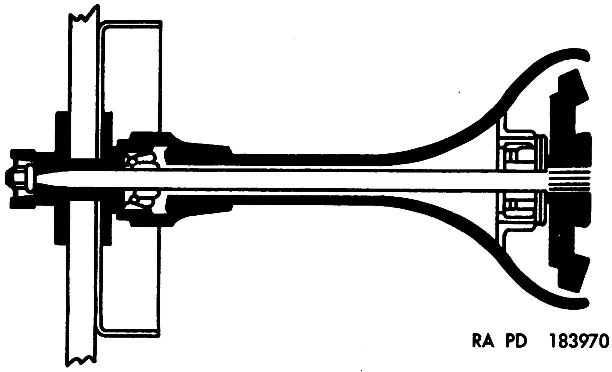


Figure 388. Semifloating rear axle.

This relieves the axle shafts of the weight of the differential and the stresses caused by its operation which are taken by the axle housing. The inner ends of the axle shafts transmit only turning effort, or torque, and are not acted upon by any other force. They are said to be *floated*. The wheels are keyed to the outer ends of the axle shafts, and the outer bearings are between them and the housing as in the plain live axle. The axle shafts take the stresses caused by turning, skidding, or wobbling of the wheels. In both the plain and semifloating live axles a wheel can come off if an axle shaft breaks or twists off.

(3) *Three-quarter floating rear axle* (fig. 389). The three-quarter floating rear axle is used on a few passenger cars. The inner ends of the axle shafts are sometimes secured with nuts and the axle shafts cannot be withdrawn without removing the differential cover. In other designs, the axle shaft can be withdrawn after the nuts holding the hub flange have been removed. The wheels, however, are supported by bearings on the outer ends of the axle tubes. The housing, instead of the axle shafts, carries the weight of the car. Since the wheel is rigidly keyed on a taper at the end of the axle shaft, as in the semifloating axle, the stresses caused by the turning, skidding, and wobbling of the wheels are still taken by the axle shaft.

(4) *Full-floating rear axle* (fig. 390). The full-floating rear axle is used on most heavy trucks. It is the same as the three-quarter floating axle, except that each wheel is carried on the end of the axle tube on two ball or roller bearings and the axle shafts are not rigidly connected to the wheels. Each wheel is driven through a dog clutch, through a spline clutch, or through a flange on the end of the axle shaft that is bolted to the outside of the wheel hub. The latter construction is frequently used but is not truly full-floating, since there is a rather rigid connection between the axle shaft and the wheel hub. With the true full-floating axle, the axle shaft transmits only the turning effort or torque. The stresses caused by turning, skidding, and wobbling of the wheels are taken entirely by the axle housing through the wheel bearings. The axle shafts can be removed and replaced without removing the wheel or disturbing the differential. Most military all-wheel drive trucks have full-floating axles.

225. Types of Rear Axle Assemblies

a. Semifloating. Figure 391 shows a semifloating rear axle of the type generally used in passen-

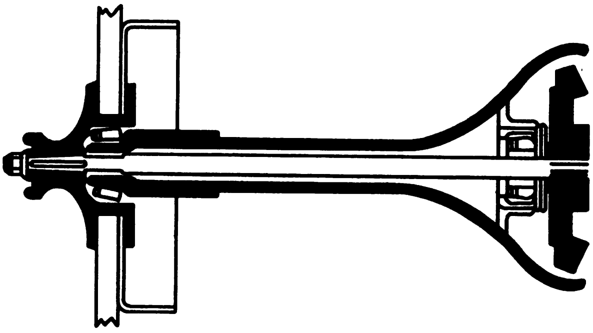


Figure 389. Three-quarter floating rear axle.

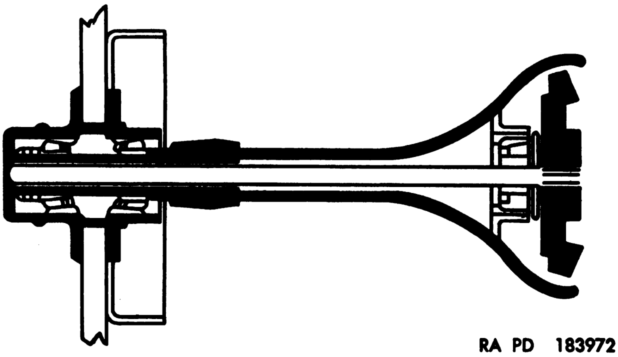


Figure 390. Full-floating rear axle.

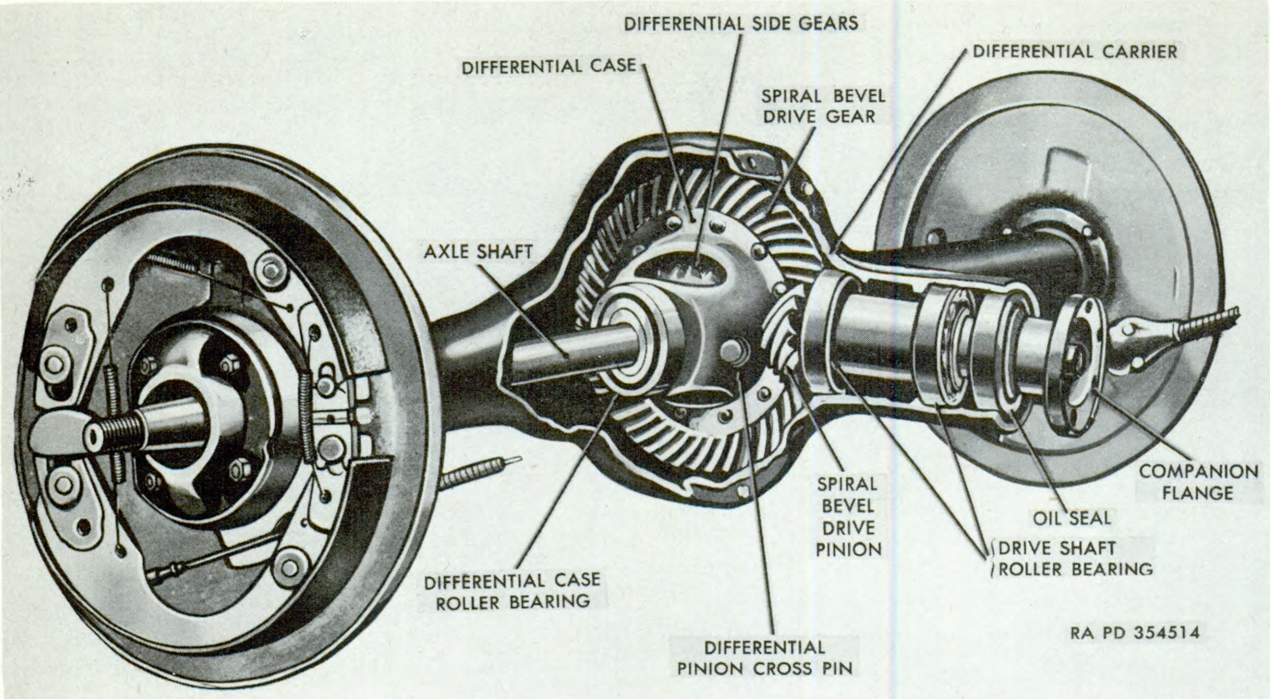


Figure 391. Semifloating rear axle with a spiral-bevel gear.

ger cars. The final drive consists of a spiral-bevel pinion and gear. Spur gears were formerly used for this purpose, but they have been generally replaced by spiral-bevel gears because these run more quietly. The drive pinion, which is connected to the propeller shaft by the companion flange (fig. 391), runs in two tapered roller bearings mounted in the differential carrier and is considered a part of the rear axle assembly. The drive pinion meshes with the spiral-bevel drive gear which is riveted to the differential case. The differential case rotates in tapered roller bearings mounted in the differential carrier. The inner races of these bearings fit on machined extensions on each side of the case and the outer races are held in brackets cast integral with the differential carrier. The differential carrier is a casting which holds the final drive and differential. It is inserted in the forward opening of the rear axle housing and fastened with cap screws through a gasket to make the joint oiltight. The axle shafts are splined to the differential side gears. Machined hub extensions on these gears rotate in plain bearings in each side of the differential case. The rear axle has two differential pinions. The path of power transmission is from the propeller shaft to the pinion drive shaft and pinion, to the spiral-bevel drive gear, to the differential case, to the differential pinions, to the differential side gears, to the axle shafts, to the wheels.

b. Hypoid. Hypoid gearing has come into rather extensive use in late years, mainly for passenger cars. A portion of a hypoid rear axle is shown in figure 392. This rear axle is practically the same as the spiral-bevel gear rear axle, except that the drive pinion and bevel drive gear are cut with a somewhat different tooth form which permits the drive pinion to mesh with the bevel drive gear below the center of the latter. This construction allows the propeller shaft to be lowered and sometimes makes a shaft tunnel in the floor of the rear compartment of the vehicle unnecessary. Due to their design, hypoid gears operate under extremely high tooth pressure and require a special hypoid lubricant.

c. Worm Gear. The worm gear rear axle (fig. 393) is used in some trucks mainly because it allows a large speed reduction. The threads on the worm are similar to screw threads and may be single, double, triple, or quadruple. The worm meshes with a worm gear having helical teeth cut in its outside circumference. The worm may be compared to a screw and the worm gear to a nut. As the worm rotates, it pulls the worm gear around. The worm is usually made of steel and the worm gear of bronze. The driving worm may be

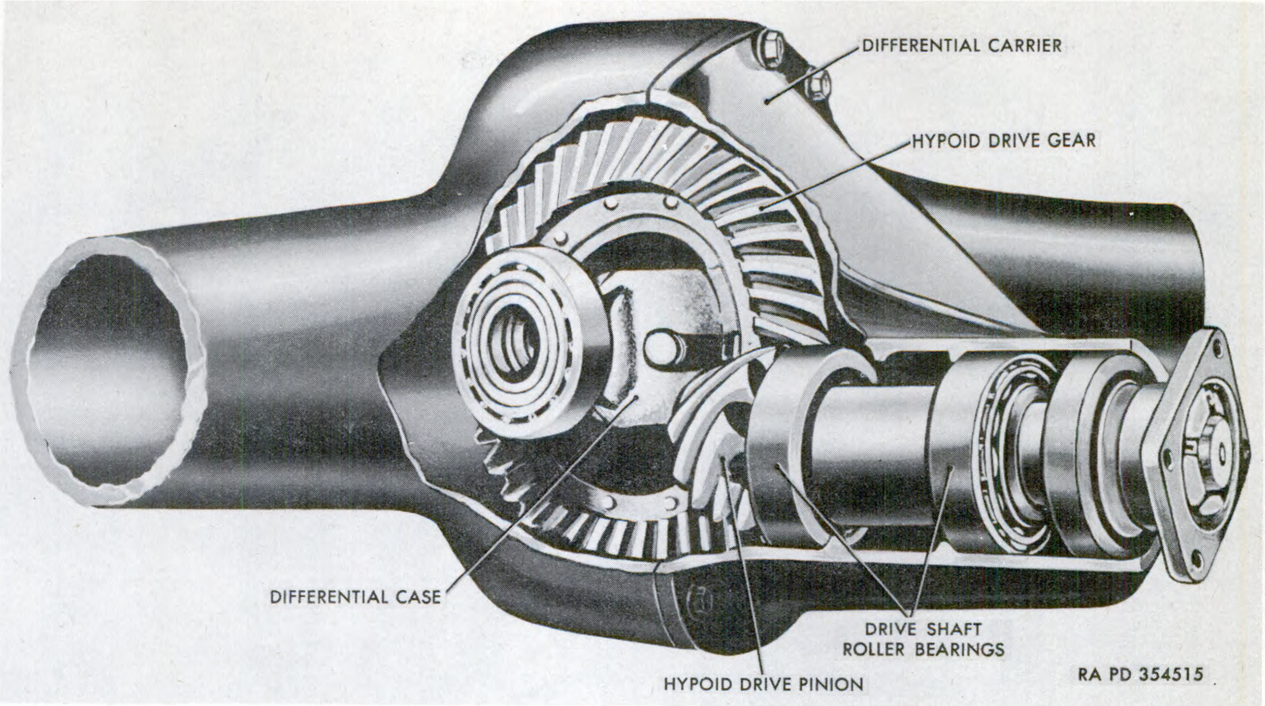


Figure 392. Hypoid rear axle.

mounted at either the top or the bottom of the worm gear. But it is usually necessary to place the worm at the top in order to allow sufficient road clearance under the rear axle housing. The rear worm bearing must be very strong and rugged since it takes the entire thrust reaction from driving the worm gear. If play develops in the worm because of wear, this bearing must also withstand repeated impact. When the vehicle is operated in reverse, or when the road wheels are driving the mechanism, the front bearing resists these forces. Sometimes a worm of hourglass form is used in the worm gear as it provides more tooth bearing surface and, consequently, less stress in the teeth.

d. Double Reduction. Double-reduction rear axles are often used for heavy-duty trucks. A usual design of the full-floating type is shown disassembled in figure 394 and in sectional view in figure 395. The first gear reduction is obtained through a spiral-bevel pinion and gear as in the common single-reduction rear axles. The bevel pinion runs in brackets mounted on the differential carrier in two roller bearings. The bevel gear is mounted rigidly on a jackshaft with a spur pinion that runs on roller bearings at each end; these are also mounted in the differential carrier. The spur pinion drives a spur gear which is bolted to the differential case. These parts are shown in their proper relative positions in figure 394. The differential and axle shafts are the same as those described in paragraphs 223 and 224.

e. Dual Ratio. Dual ratio, or two-speed, rear axles are sometimes used on trucks and passenger cars. They contain two different gear ratios which can be selected at will by the driver, usually by a manual-control lever. A dual-ratio rear axle serves the same purpose as the auxiliary transmission described in paragraph 211 and, like the latter, it doubles the number of gear ratios available for driving the vehicle under the various load and road conditions. This type rear axle is shown in a cross sectional view in figure 396. It is driven by the conventional spiral-bevel pinion and differential drive ring gear, but a planetary gear train is placed between the differential drive ring gear and differential case. The internal gear of the planetary train is rigidly bolted to the bevel drive gear. A ring on which the planetary gears are pivoted is bolted to the differential case. A member, consisting of the sun gear and a dog clutch, slides on one of the axle shafts and is usually controlled by a hand lever accessible to the driver. When this sliding part is in the high-ratio position, the sun gear meshes with internal teeth on the ring carrying the planetary gears and disengages the dog clutch from the

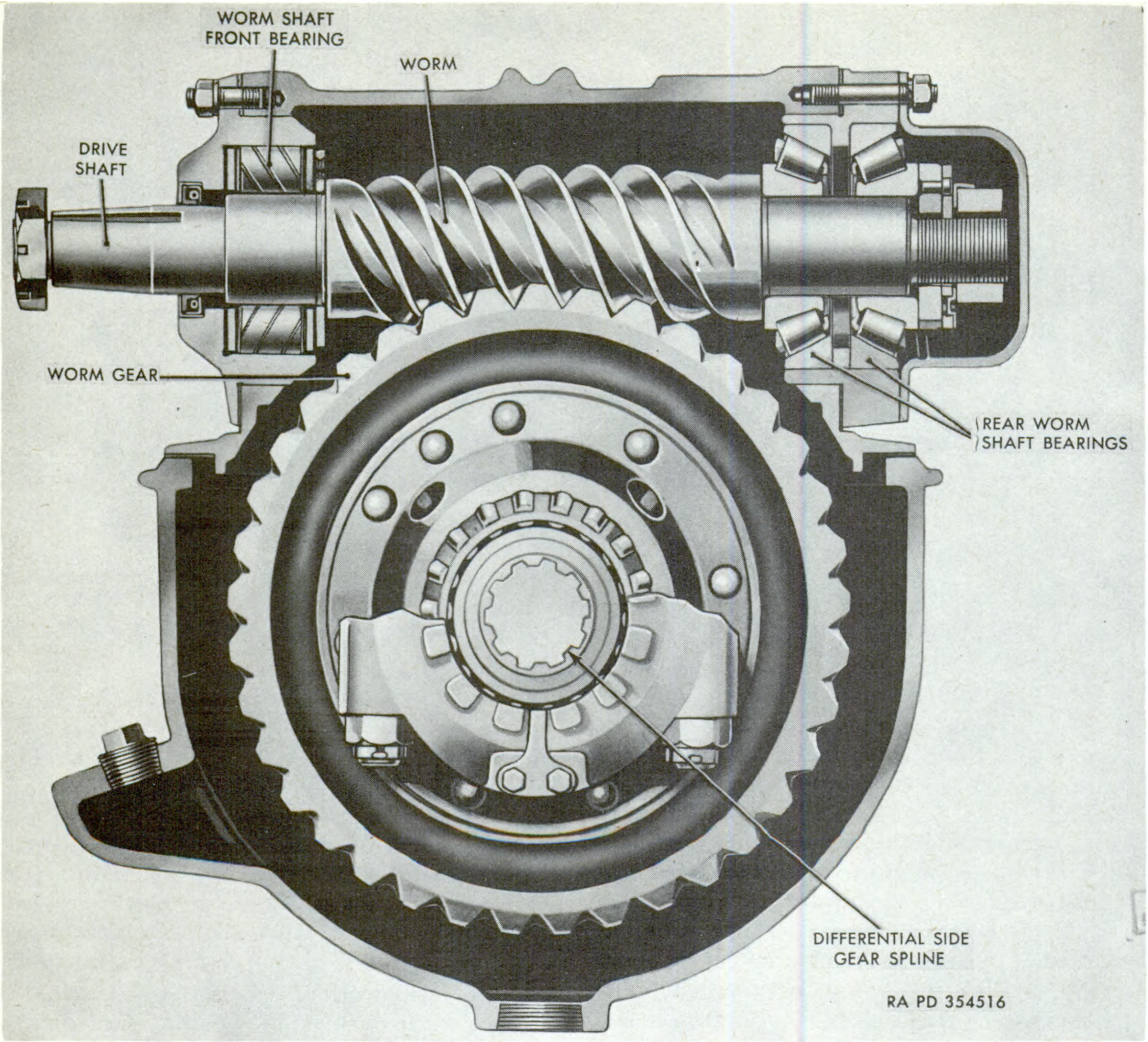


Figure 393. Worm gear rear axle.

left bearing adjusting ring which is rigidly held in the differential carrier. In this position (fig. 397), the planetary gear train is locked together, there is no relative motion between the gears in the planetary train, and the differential case is driven directly by the differential drive ring gear the same as in the conventional single-ratio rear axle. In the low-ratio position (fig. 398), the sun gear is slid out of mesh with the ring carrying the planetary gears, and the dog clutch makes a rigid connection with the left bearing adjusting ring. Since the sun gear is integral with the dog clutch, it is also locked fast to the bearing adjusting ring and remains stationary. The internal gear rotates the planetary gears around the stationary sun gear and the differential case is driven by the ring on which the planetary gears are pivoted. This action produces the gear reduction, or low speed, of the axle.

f. Double-Reduction, Dual-Ratio. Double-reduction, dual-ratio rear axles are also sometimes used in heavy-duty motor vehicles. Rear axles of this type combine the features of the double-reduction and dual-ratio axles in one unit. A popular design is shown in figure 399, with part of the differential housing cut away. A spiral-bevel pinion drives a jackshaft through a spiral-bevel drive gear. Two helical pinions of differ-

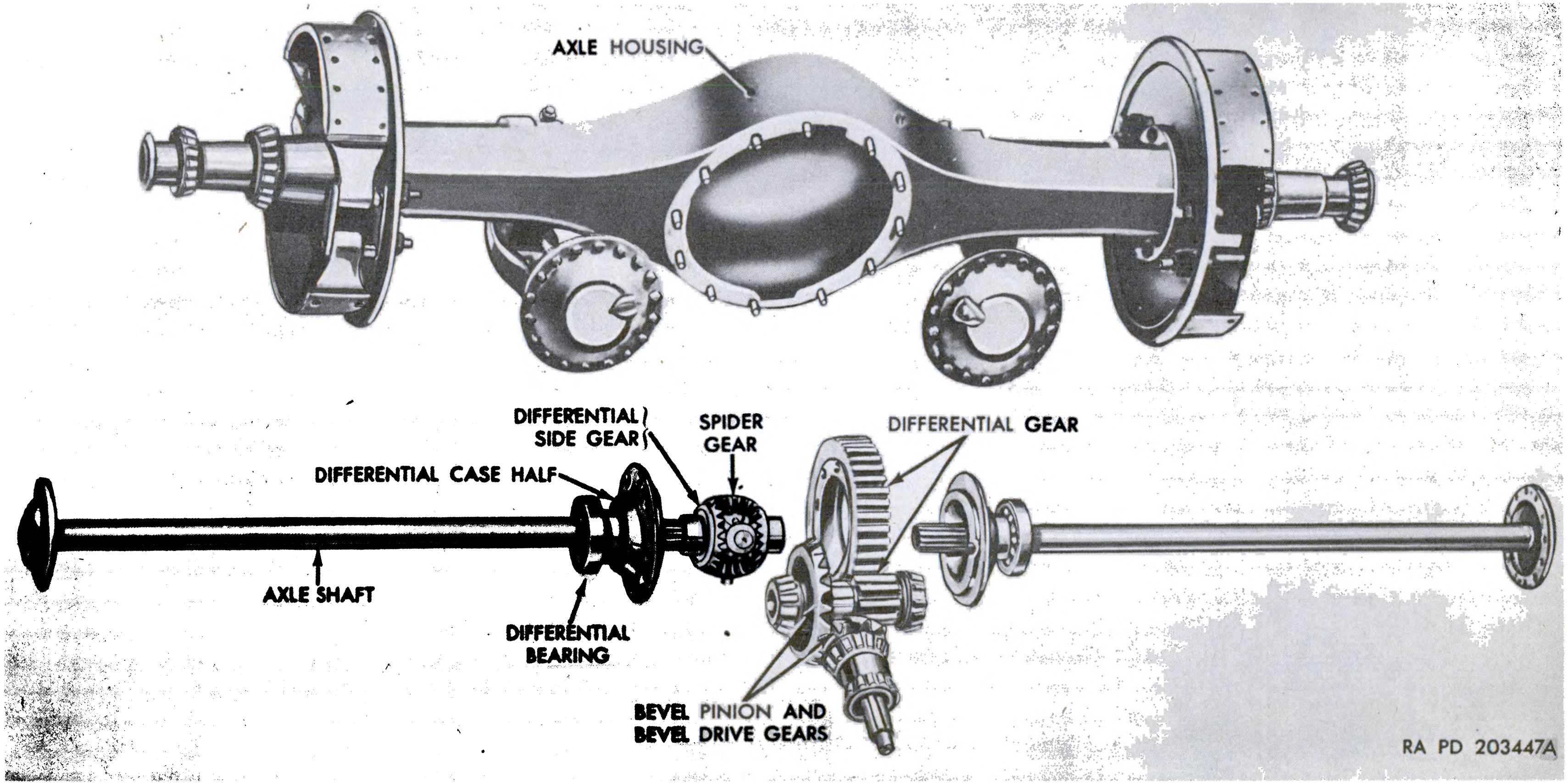

AXLE HOUSING
DIFFERENTIAL SIDE GEAR
SPIDER GEAR
DIFFERENTIAL GEAR
DIFFERENTIAL CASE HALF
AXLE SHAFT
DIFFERENTIAL BEARING
BEVEL PINION AND BEVEL DRIVE GEARS
RA PD 203447A

Figure 394. Gear arrangement in double-reduction rear axle—exploded view.

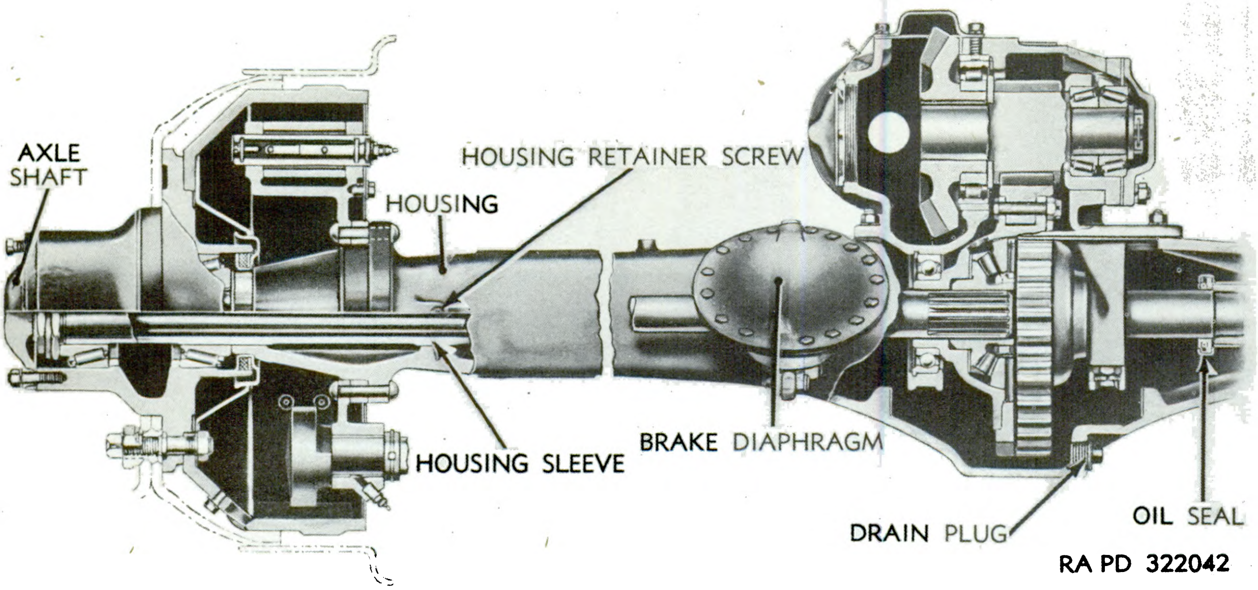


Figure 395. Gear arrangement in double-reduction rear axle—assembled view.

ent sizes and a 2-way dog clutch are mounted on the jackshaft. The two helical pinions are not fast to the jackshaft but rotate freely on it on bearings. They are in constant mesh with two helical gears of correspondingly different sizes, both rigidly mounted on the differential case. The sliding dog clutch is controlled by a hand lever and clutches either one of the helical pinions fast to the jackshaft. The clutch is shown in the low-speed position in figure 399. The drive is from the propeller shaft to the drive pinion, to the bevel drive gear, to the jackshaft, to the right helical pinion, to the right helical gear, to the differential case, to the differential pinions, to the differential side gears, to the axle shafts, to the wheels. When the dog clutch is in the high-speed position (moved to the left), the drive is the same except that it is through the other pair of helical gears.

226. Four-Rear-Wheel Drives

a. Motor vehicles that carry extremely heavy loads are often equipped with four rear wheels in order to increase traction and to avoid excessive weight on the rear tires; that is, the weight of the load is divided among twice as many tires as when only one rear axle is used. Dual wheels are generally used with this arrangement; therefore, the weight of the rear of the vehicle and load is divided among eight tires instead of four.

b. Different spring suspensions are used but the bogie is most general. A bogie consists of two axles jointed by a trunnion axle. The trunnion axle passes directly beneath the rear cross member of the frame.

c. Vehicles having this equipment may be either 4- or 6-wheel drive. Sometimes the dual rear axles are driven by independent propeller shafts (fig. 400) from a transfer assembly. In this case, the propeller shaft to the rearmost rear axle is divided into three parts, the short middle part passing through bearings mounted on the forward rear axle. The transfer assembly may contain an interaxle differential, but usually does not.

d. Another arrangement is the tandem drive (figs. 401, 402, and 403), employing double-reduction axles. A single propeller shaft from the transmission transfer assembly is connected to the forward rear-axle drive pinion through a shaft, and another short interaxle propeller shaft connects the drive pinion shaft of the forward rear axle with the drive pinion shaft of the rearward rear axle. Ordinarily, no interaxle differential is used, but one which is built into the forward rear axle is sometimes used. With the tandem drive, no transfer assembly is required if the vehicle drives on the four rear wheels only. If the front wheels are also driven, a transfer assembly is required.

227. Front-Wheel Drives

a. In 4- or 6-wheel drives, the front wheels are driven through a driving axle assembly very simi-

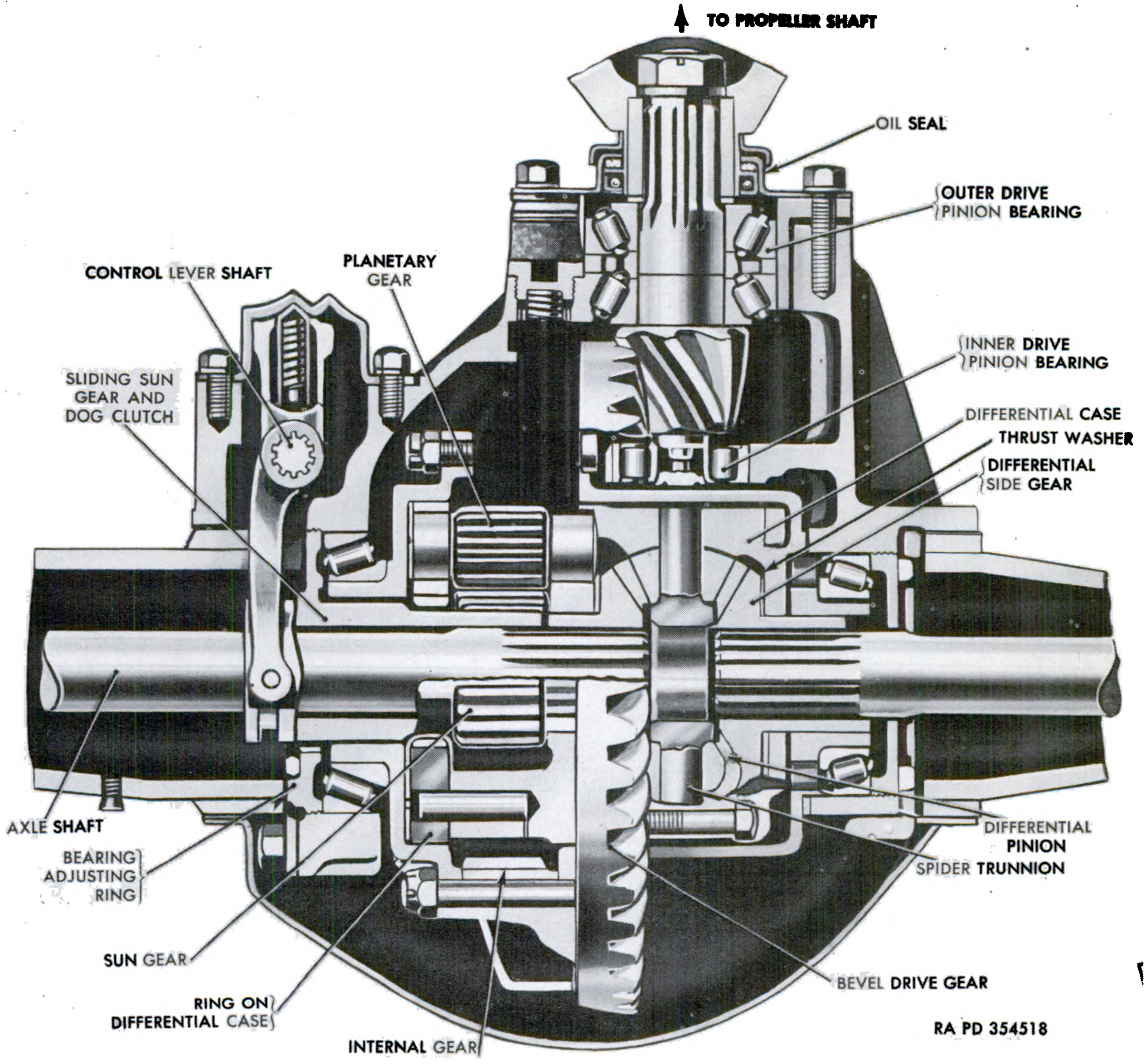

TO PROPELLER SHAFT
OIL SEAL
OUTER DRIVE PINION BEARING
CONTROL LEVER SHAFT
PLANETARY GEAR
INNER DRIVE PINION BEARING
SLIDING SUN GEAR AND DOG CLUTCH
DIFFERENTIAL CASE
THRUST WASHER
DIFFERENTIAL SIDE GEAR
AXLE SHAFT
BEARING ADJUSTING RING
DIFFERENTIAL PINION
SPIDER TRUNNION
SUN GEAR
BEVEL DRIVE GEAR
RING ON DIFFERENTIAL CASE
RA PD 354518
INTERNAL GEAR

Figure 396. Dual-ratio rear axle.

lar to a rear axle. It may be of the single- or double-reduction type. Figures 284, 285, and 404 show a usual arrangement of transfer assembly, propeller shafts, universal joints, driving axles, and springs for a 4-wheel-drive or 6-wheel-drive vehicle. Front-wheel drives are ordinarily Hotchkiss drives with the front springs pivoted at the rear and shackled at the front. Axles are of the full-floating type. As in the case of rear live axles, the axle housings are usually built up, but they may be pressed steel for light vehicles and single-piece castings for extremely heavy-duty vehicles. The split-type housing is frequently used. The principal difference between front live axles and rear axles is that in front-wheel drives provision must be made for steering. In rear driving axles, the axle shafts are directly connected to the wheels. Since the front wheels must turn on the steering knuckle pivots, they are usually driven by the axle shafts through universal joints (par. 216) concentric with the steering knuckle pivots. Figure 405 shows the housings of the steering knuckle pivots and constant-velocity universal joints, as well as the tie rod, brakedrums, hub flanges, and wheel mounting studs for a typical front live axle assembly.

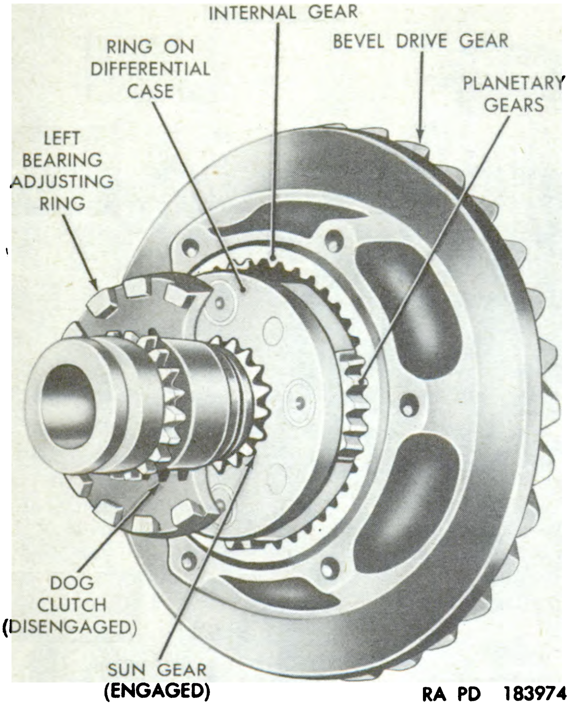

INTERNAL GEAR
RING ON DIFFERENTIAL CASE
BEVEL DRIVE GEAR
PLANETARY GEARS
LEFT BEARING ADJUSTING RING
DOG CLUTCH (DISENGAGED)
SUN GEAR (ENGAGED)
RA PD 183974

Figure 397. Position of gears for high ratio.

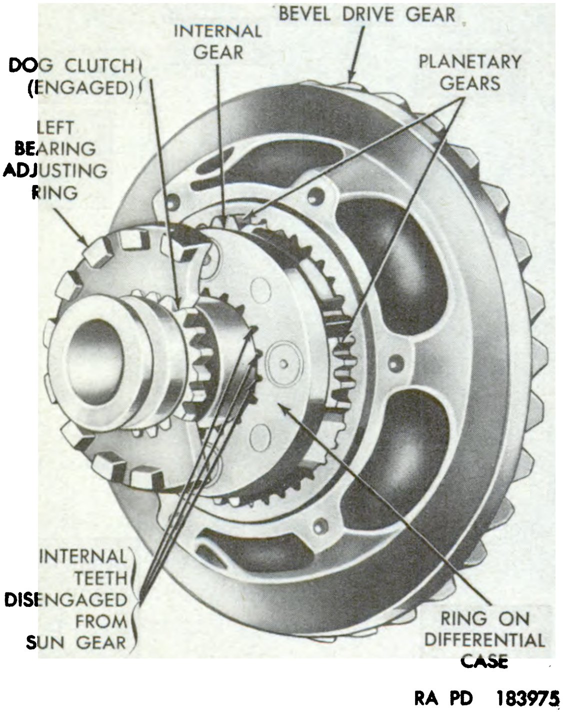

BEVEL DRIVE GEAR
INTERNAL GEAR
DOG CLUTCH (ENGAGED)
PLANETARY GEARS
LEFT BEARING ADJUSTING RING
INTERNAL TEETH DISENGAGED FROM SUN GEAR
RING ON DIFFERENTIAL CASE
RA PD 183975

Figure 398. Position of gears for low ratio (planetary gears are free to rotate).

b. A type of front-wheel drive which drives the front wheels through gearing and permits them to steer without the use of a universal joint is shown in figure 406. It has been used to a very limited extent. A spiral-bevel pinion keyed to the end of the axle shaft drives the lower half of a double bevel gear on the lower end of the steering knuckle pivot. The top half of the double gear meshes with a fourth gear that is integral with the wheel hub. The gear and hub turn on the steering knuckle. When the wheels are cramped, the bevel gear on the wheel hub rotates around the bevel gear on the steering knuckle pivot.

c. Constant-velocity universal joints, used with front-wheel drives to avoid strain on the steering mechanism, are discussed in chapter 16.

228. Interwheel Differential

One of the latest developments in front-wheel drives is dual wheels having an interwheel differ-

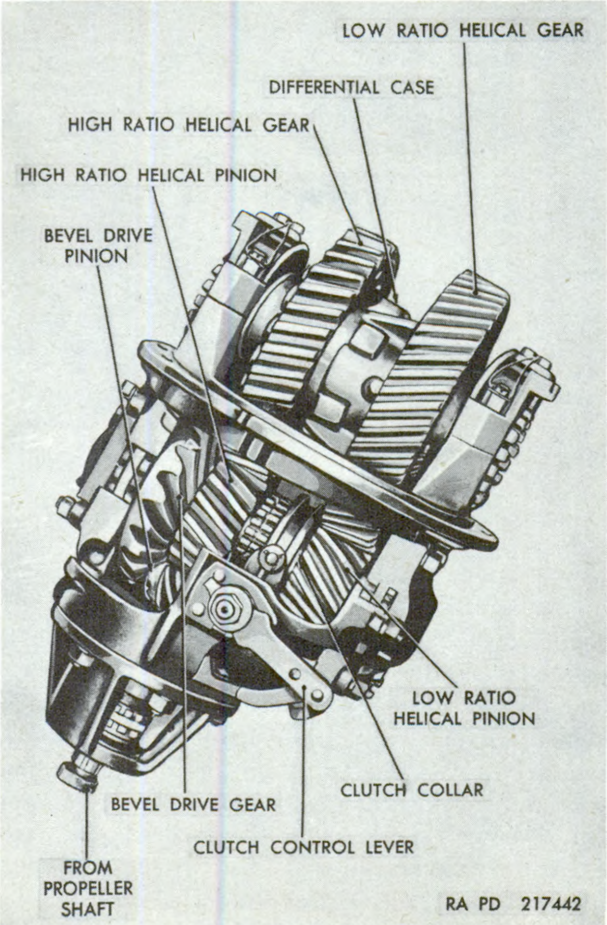

LOW RATIO HELICAL GEAR
DIFFERENTIAL CASE
HIGH RATIO HELICAL GEAR
HIGH RATIO HELICAL PINION
BEVEL DRIVE PINION
LOW RATIO HELICAL PINION
CLUTCH COLLAR
BEVEL DRIVE GEAR
CLUTCH CONTROL LEVER
FROM PROPELLER SHAFT
RA PD 217442

Figure 399. Double-reduction dual ratio rear axle.

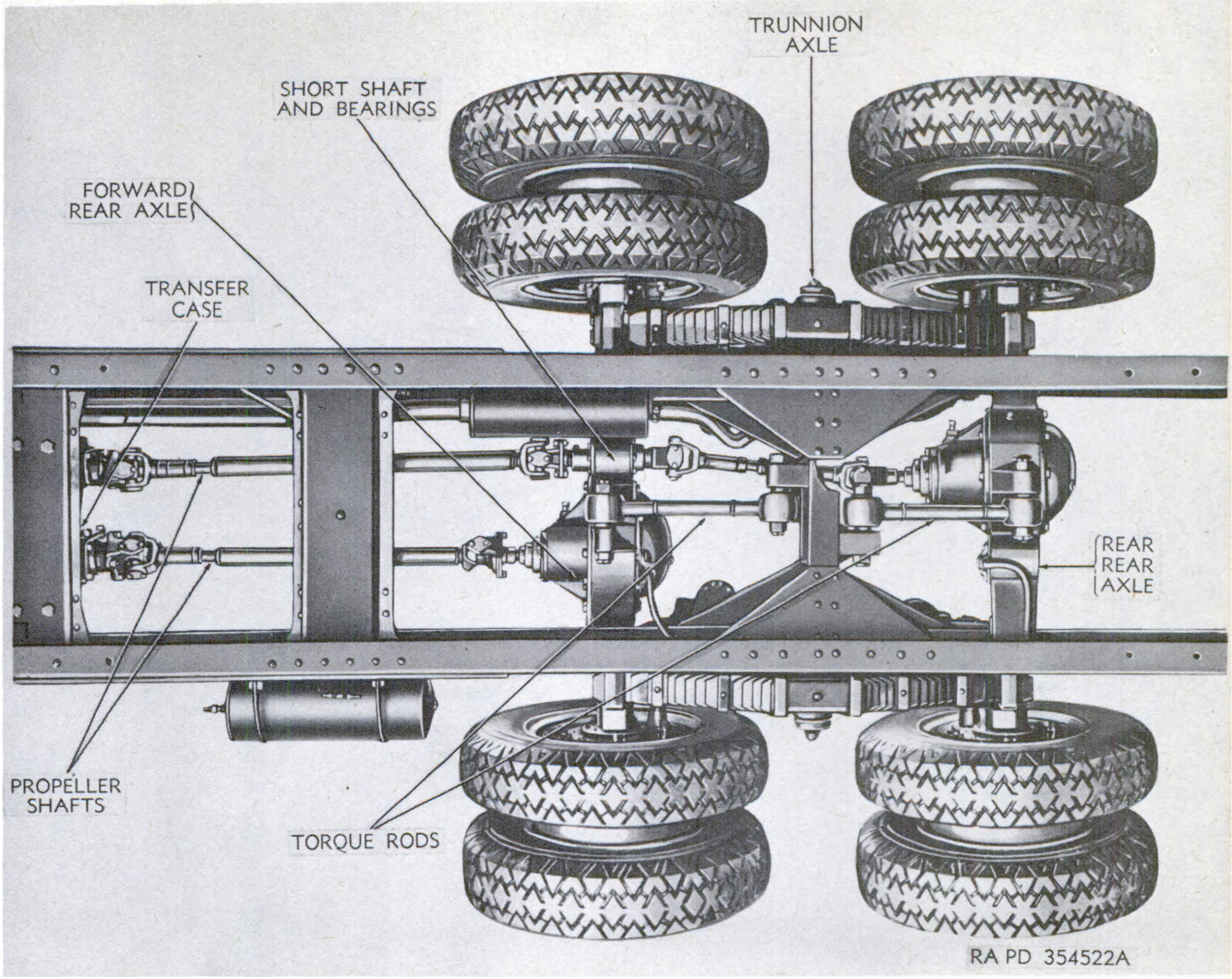


Figure 400. Bogie 4-wheel drive with independent propeller shafts.

ential which makes them easily steerable. Each wheel is equipped with its own brake. Vertical steering knuckle pivots are used. The differential is of the spur gear type, the pinions having a tooth form that gives it the same action as the high-traction differential described in paragraph 218*c*. When dual front wheels are used in addition to dual rear wheels, a greater portion of the total load can be carried by the front axle. This makes possible a greater payload without increasing the overall length of the vehicle. Interwheel differentials can also be used for front dead axles, live rear axles, tandem rear live axles, and trailer dead axles to provide for the difference in distance traveled by each of the pair of dual wheels in rounding curves, and for the different rolling radius of each of the dual wheels caused by the crown of the road, ruts, etc. It is thought that a great saving in tire wear results, because of the elimination of slippage which must occur when dual wheels are rigidly bolted together.

229. Power Divider

a. The forward rear axle is of the full-floating, double-reduction type having a spiral-bevel pinion and gear for the first reduction, and a spur pinion and gear for the second reduction. The spiral-bevel pinion is driven through a power divider which also drives the rearward rear axle through a shaft that passes through the pinion of the forward rear axle, and is attached to the forward end of the interaxle drive shaft (fig. 403).

b. The power divider is attached to the forward end of the gear carrier, which is mounted on the upper side of the axle housing. Both forward and rear axles are driven from the forward drive flange through the power divider by means of a driving cage carrying two parallel rows of radial

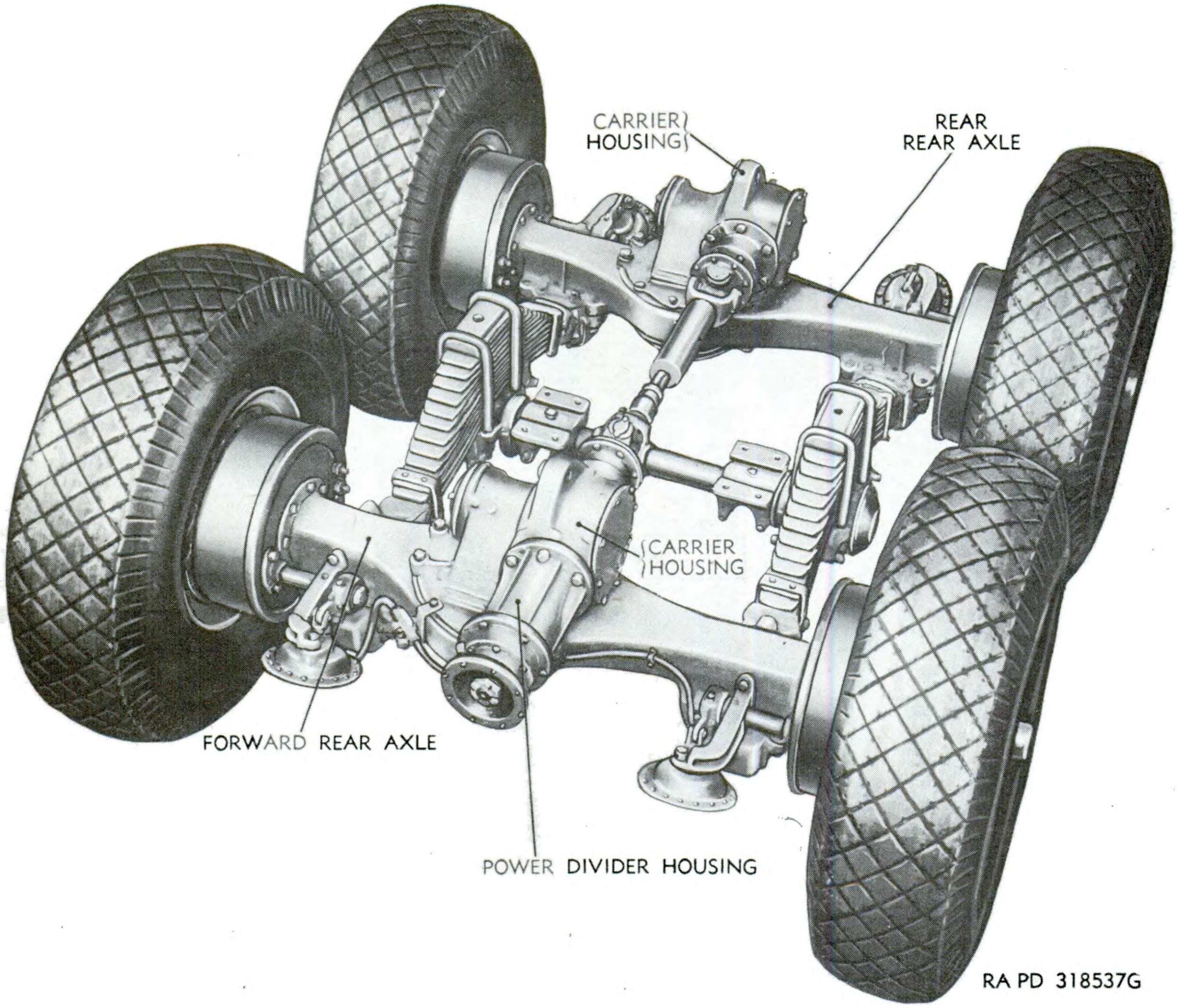

CARRIER HOUSING
REAR REAR AXLE
CARRIER HOUSING
FORWARD REAR AXLE
POWER DIVIDER HOUSING
RA PD 318537G

Figure 401. Tandem dual-rear-axle arrangement with double-reduction final drives and power divider.

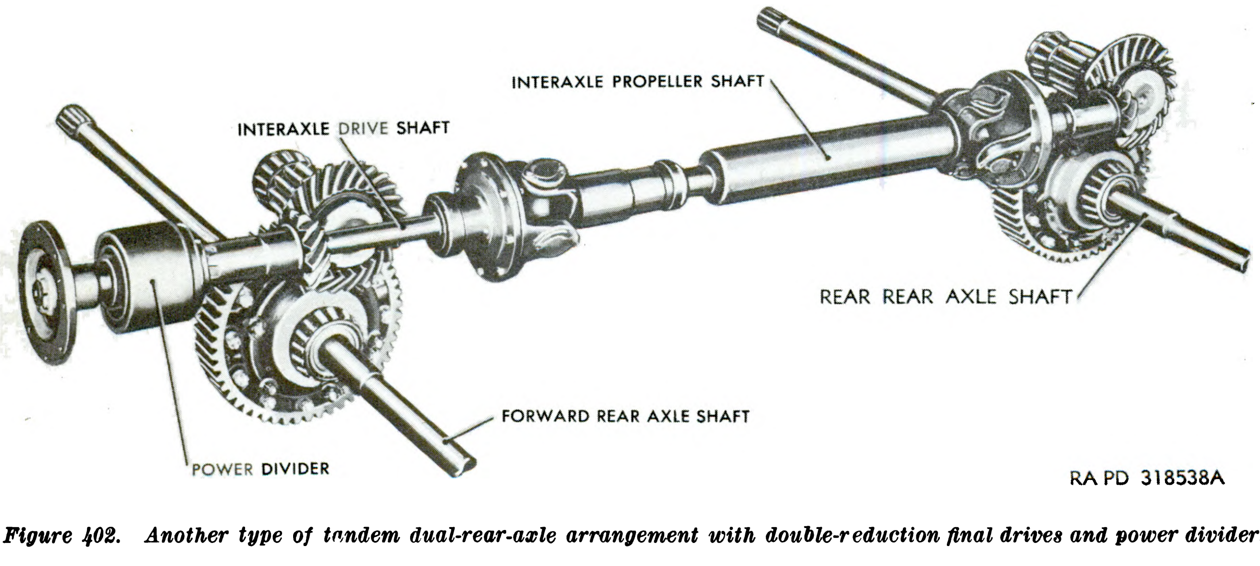

INTERAXLE PROPELLER SHAFT
INTERAXLE DRIVE SHAFT
REAR REAR AXLE SHAFT
FORWARD REAR AXLE SHAFT
POWER DIVIDER
RA PD 318538A

Figure 402. Another type of tandem dual-rear-axle arrangement with double-reduction final drives and power divider.

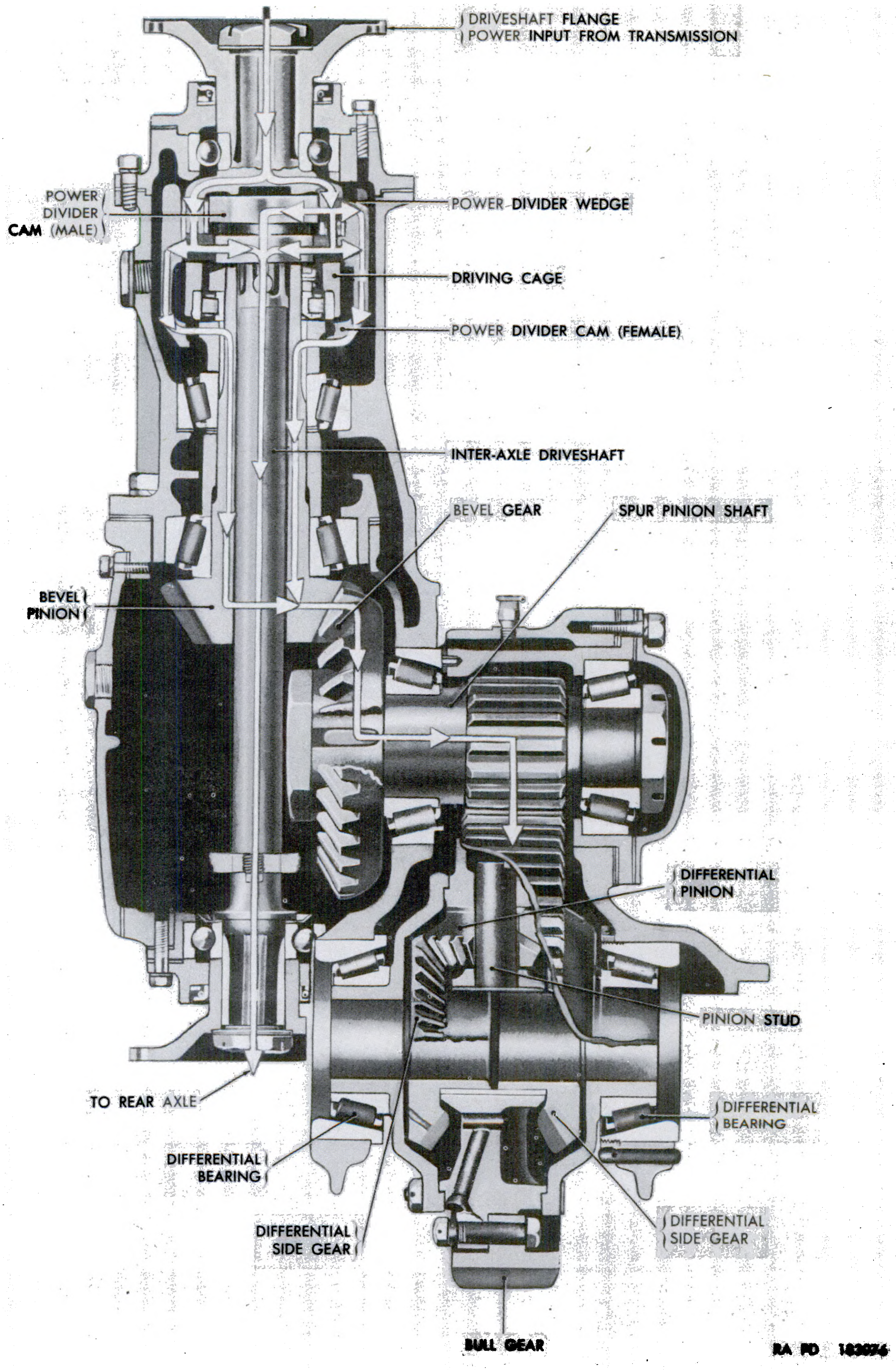

DRIVESHAFT FLANGE
POWER INPUT FROM TRANSMISSION
POWER DIVIDER CAM (MALE)
POWER DIVIDER WEDGE
DRIVING CAGE
POWER DIVIDER CAM (FEMALE)
INTER-AXLE DRIVESHAFT
BEVEL GEAR
SPUR PINION SHAFT
BEVEL PINION
DIFFERENTIAL PINION
PINION STUD
TO REAR AXLE
DIFFERENTIAL BEARING
DIFFERENTIAL BEARING
DIFFERENTIAL SIDE GEAR
DIFFERENTIAL SIDE GEAR
BULL GEAR
RA PD 182076

Figure 403. Gear carrier and power divider—cross sectional view.

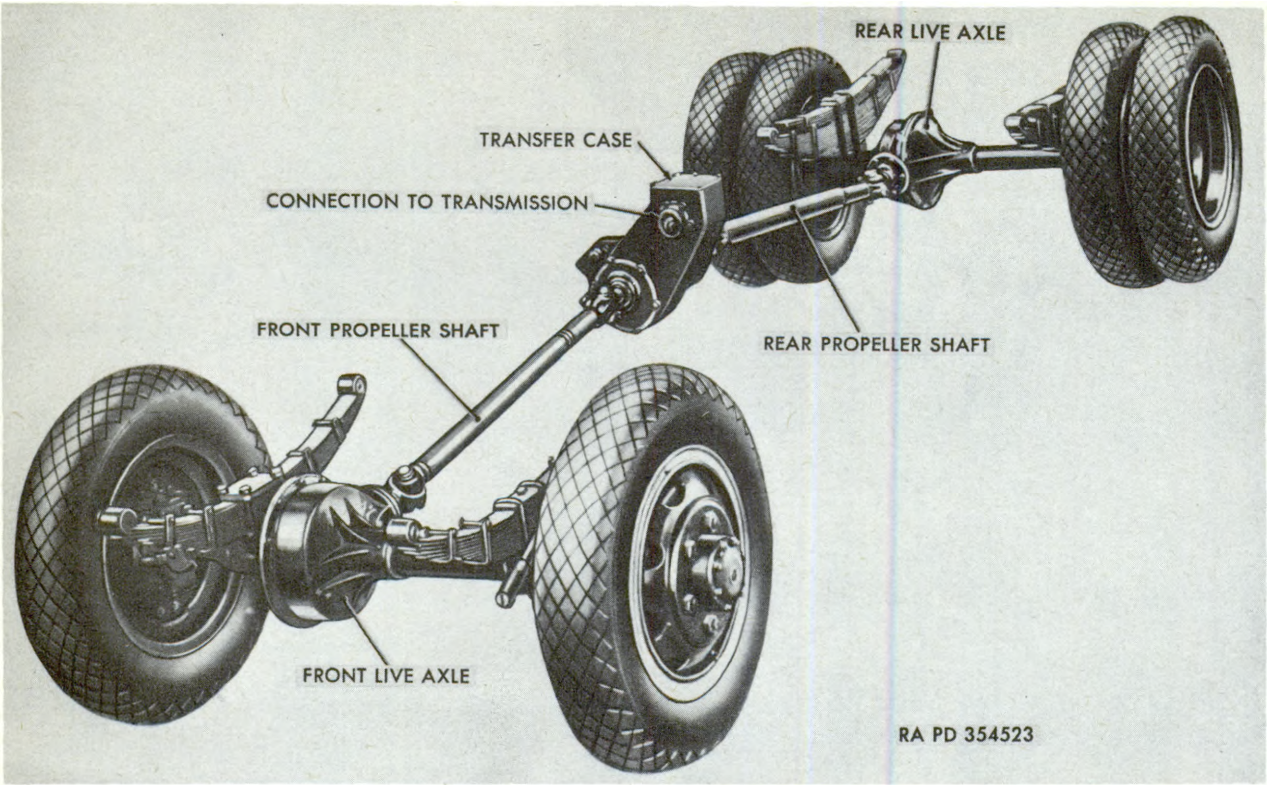

REAR LIVE AXLE
TRANSFER CASE
CONNECTION TO TRANSMISSION
FRONT PROPELLER SHAFT
REAR PROPELLER SHAFT
FRONT LIVE AXLE
RA PD 354523

Figure 404. Arrangement of transfer assembly, propeller shafts, universal joints, and live axles for 4-wheel drive.

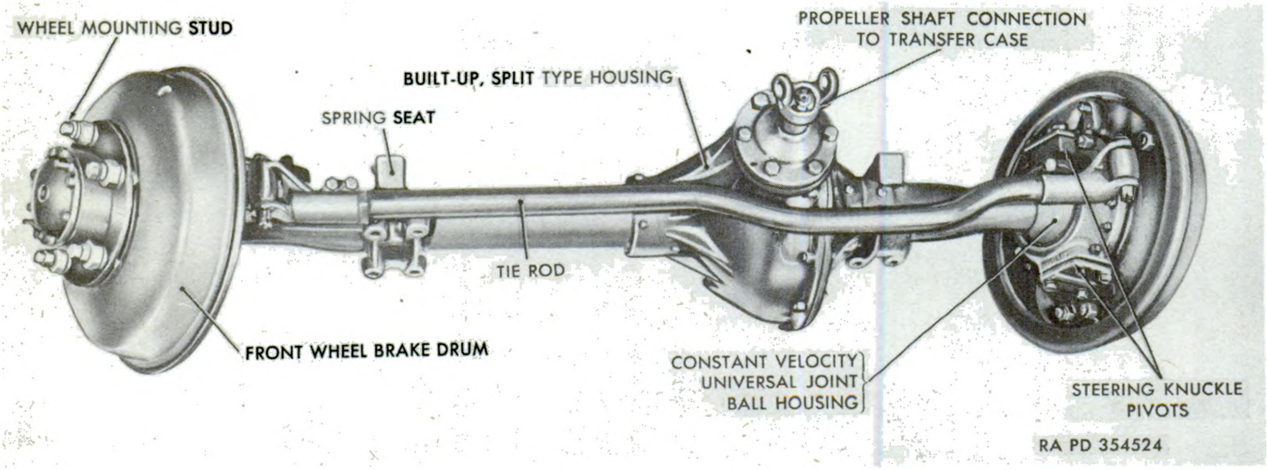

WHEEL MOUNTING STUD
PROPELLER SHAFT CONNECTION TO TRANSFER CASE
BUILT-UP, SPLIT TYPE HOUSING
SPRING SEAT
TIE ROD
FRONT WHEEL BRAKE DRUM
CONSTANT VELOCITY UNIVERSAL JOINT BALL HOUSING
STEERING KNUCKLE PIVOTS
RA PD 354524

Figure 405. Front live axle assembly.

wedges or plungers engaging at their outer ends with internal (female) cams on a cage which drives the bevel pinion of the forward rear axle. At their inner ends the plungers engage with external (male) cams on the interaxle drive shaft which drives the bevel pinion of the rear axle. Due to the wedging action between the cams and the plungers, they rotate together with no relative movement, unless running conditions require a differential action.

c. Whenever either the forward or the rear pair of wheels tends to run ahead of the other pair, due to slippage or uneven road surfaces, there is a relative movement of the external and internal cams, which is permitted by the sliding of the radial plungers in the driving cage. This restricted movement provides a differential action which apportions the driving effort to the two pairs of wheels to provide the maximum tractive effort. The wheel spindles are pressed into the

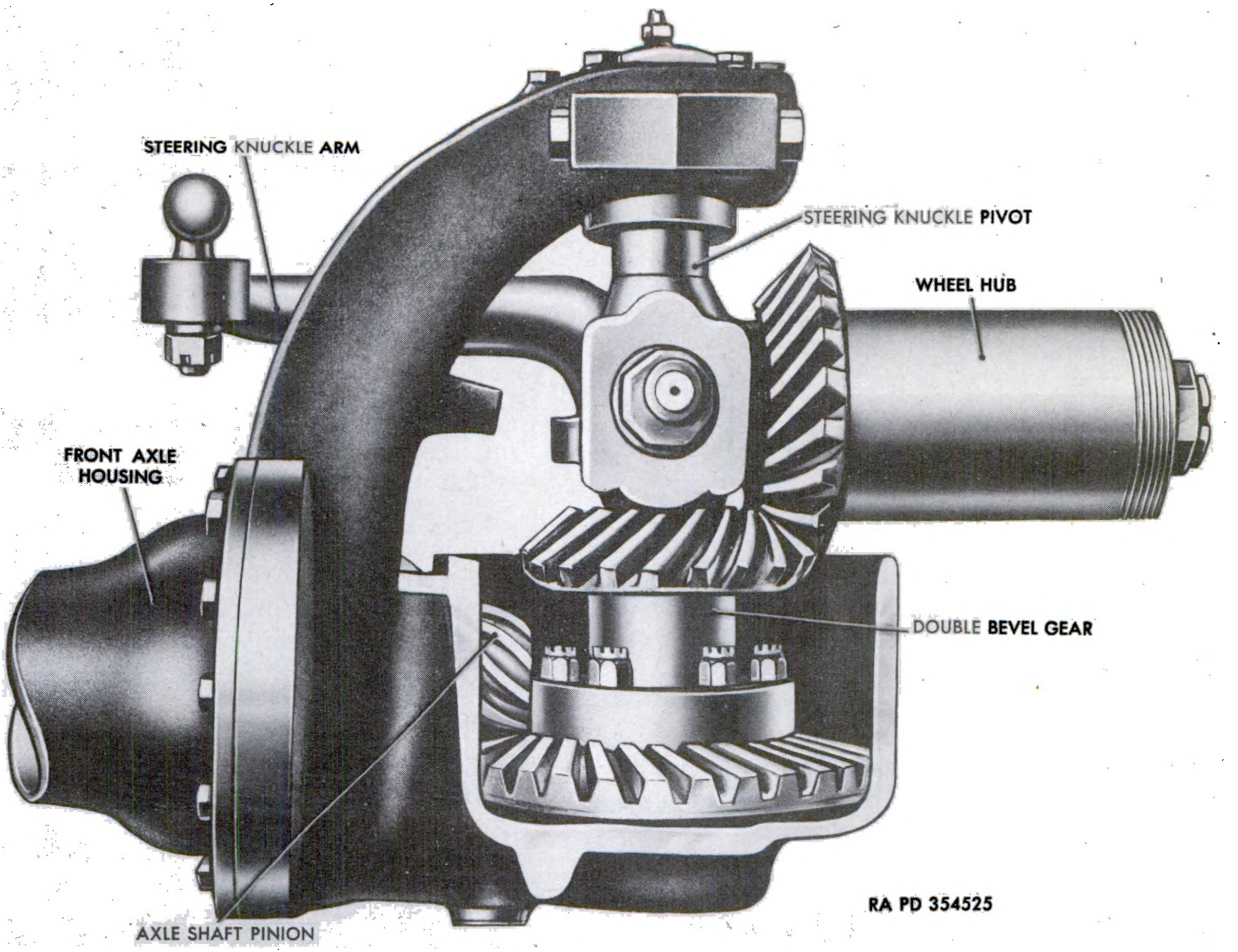


Figure 406. Helical gear steering for front wheel drive.

axle housing, and the brake assemblies are carried by integral flanges. The underslung springs, which tie the two rear axle housings together in parallel relation, are attached by means of rubber shock insulators set in sockets on the bottom of the housing, and retained by caps.

d. A ball-joint torque rod, between the top of the gear carrier housing and a chassis frame cross member, takes the torque imparted to the axle assembly by the driving and braking.

230. Tracklaying Vehicle Final Drive

a. In tanks the final drive works very much the same as in a wheeled vehicle. The driving axle is splined into the compensating gear of the differential (figs. 381, 382, and 383), or is connected to it by a propeller shaft, and has a herringbone or spur gear on the outside end. Forward of this gear, and meshing with it, is a driven gear to which the driving sprocket of the tank is attached. Each gear shaft is supported by a combination of ball and plain roller bearings.

b. The sprocket itself is worthy of mention, because it is the final connection between the power train and the tank track. With steel teeth meshing between each connecting link of the track, the power train sequence is completed and the vehicle is moved along.

Section III. WHEELED VEHICLE PERFORMANCE

231. General

There are many different aspects of vehicle performance. Miles per gallon of fuel, miles per hour in first, second, or other gear ratio, and the amount of weight a vehicle can carry are all commonly considered factors. Other factors of equal importance include tractive factor, grade ability, and drawbar pull. These three factors refer to less-known performance aspects that should be further considered.

232. Performance Factors

a. Tractive Factor.

(1) Tractive factor refers to the pushing effort the wheels can make against the ground as a result of the application of torque to them through the power train from the engine. Actually, the tractive factor is given in pounds-of-push for each pound of vehicle weight. Tractive factor can be determined by the following formula:

$$\text{Tractor factor} = \frac{ET \times R \times 0.85}{GW \times TLR}$$

where ET = Engine torque from dynamometer tests, with at least distributor and water pump operating (lb-ft).

R = Gear ratio at reduction under consideration.

0.85 = Efficiency of power transmission (arbitrarily chosen as an average value).

GW = Gross vehicle weight (lbs).

TLR = Tire loaded radius (ft.).

(2) Suppose, for example, that we wanted to figure the tractive factor of a ¼-ton 4x4 utility truck. We can determine it in any gear we like, and with the truck loaded or unloaded. The tractive factor will increase with increased gear ratio, and will decrease as the vehicle is loaded. Generally, the tractive factor is figured with maximum payload since this gives an indication of the vehicle performance under the most adverse conditions. However, for our purpose let us calculate the tractive factor of the ¼-ton 4x4 truck at maximum gear reduction and unloaded. Unloaded, the vehicle weighs 2,625 pounds. The engine torque is 79 pound-feet. The gear reduction in the transmission in low gear is 2.798 : 1; in the transfer in low range, 2.43 : 1, and in the differentials, 5.38 : 1. Total gear reduction is 36.7 : 1, in low range, low gear. Tire radius is 1.25 feet, unloaded; and slightly less, loaded. However, let us use the figure 1.25 feet for ease of figuring. Substituting all this data in the formula gives us:

$$\text{Tractive factor} = \frac{79 \times 36.7 \times 0.85}{2{,}625 \times 1.25} = 0.75$$

(3) This figure means the tires can exert a push against the ground of 0.75 pound for every pound of vehicle weight. If the tires do not slip, the vehicle can be pushed forward 0.75 pound for every pound of vehicle weight.

b. Grade Ability.

(1) Grade ability refers to how steep a grade the vehicle can climb. Grade, itself, is referred to in percent: a 10 percent grade, or a 26 percent grade, for example. A 1 percent grade rises 1 foot in every 100 feet. A 26 percent grade rises 26 feet in every 100 feet. If the tractive factor is known, the grade ability can be easily figured by use of the formula:

$$\text{Grade ability} = (\text{Tractive factor} - 0.015) \times 100.$$

where 0.015 equals rolling resistance per pound of vehicle weight (arbitrarily chosen as an average value).

(2) Suppose we wanted to figure the maximum grade ability of the ¼-ton, 4 x 4 truck for which we just calculated that the tractive factor (maximum) was 0.75. Substituting in the formula would give us:

$$\text{Grade ability} = (0.75 - 0.015) \times 100 = 0.735 \text{ or } 73.5 \text{ percent.}$$

(3) The truck, unloaded and in low range, low gear, could go up a 73.5 percent grade, that is, a grade that rises 73.5 feet every hundred feet. It can be seen that the grade ability of a vehicle will vary with the load and the gear ratio. It will decrease as the vehicle is loaded and increase as gear ratio is increased.

c. Drawbar Pull.

(1) The drawbar pull is an indication of how much the vehicle can pull on a trailer attached to it. Drawbar pull can be calculated if the tractive factor and weight on powered wheels are known by use of the following formula:

$$\text{Drawbar pull} = \text{Tractive factor} \times \text{weight on powered wheels.}$$

(2) In the vehicle under discussion (¼-ton 4 x 4 truck), we determined that the maximum tractive factor was 0.75 with a vehicle weight of 2,625 pounds. Since all wheels are powered, multiplying these two figures together gives the drawbar pull, or 0.75 x 2,625 pounds equals 1,970 pounds. That is, the vehicle can produce a maximum drawbar pull of 1,970 pounds (provided, of course, that no wheels slip). Note that, if the vehicle itself is loaded, it will tend to increase the drawbar pull; however, at the same time, loading the vehicle reduces the tractive factor. If, for example, we were to add a 1,000-pound load to the vehicle, giving a gross weight of 3,625 pounds, we would find that the tractive factor drops to approximately 0.55. This, times 3,625 pounds, gives a maximum drawbar pull of approximately 1,970 pounds. Thus, we find for a vehicle having all-wheel drive, the drawbar pull is a constant regardless of the weight carried by the vehicle. Note that the term *maximum* has been used here; this means that the vehicle could supply this amount of pull. However, in actual performance, the vehicle is not required to supply this amount of drawbar pull. The applicable technical manual for any vehicle specifies the maximum trailer load to be attached. The ¼-ton 4 x 4 truck under analysis, for example, has a maximum limit of 2,000 pounds trailer load on the highway (1,500 pounds cross-country).

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PART FIVE
CHASSIS COMPONENTS
CHAPTER 18
SUSPENSION SYSTEMS

Section I. INTRODUCTION

233. Purpose of Suspension Systems

The purpose of the suspension system of a vehicle is to support the weight of that vehicle. It is therefore an important part of any vehicle, and is particularly important in military vehicles, which are often very heavy and must be able to traverse all types of terrain. Since tanks and armored cars are really mobile gun platforms, the suspension systems of these vehicles must provide stability even when the vehicles are moving over rough ground. In wheeled vehicles the suspension must provide not only for absorption of road shocks, but must allow the driver to steer the vehicle; and also must be efficient over a wide range of speed and load conditions. In tracklaying vehicles, the system must support the vehicle in such manner that the immense weight will not cause bogging down even in soft ground, and must provide stability as well as protection from bumps and jolts. Figures 407 and 408 illustrate how a tracklaying vehicle passes over a 12-inch obstruction. Note that this rise is absorbed entirely by the suspension system; that is, the vehicle itself is not raised.

234. Types of Suspension Systems

To meet the wide variety of requirements imposed by military situations, many systems have been designed and found efficient. These may be divided into independent axle, bogie axle, independent wheel, single arm, torsion bar, double arm, and double articulated arm.

235. Principal Parts of Suspension Systems

The parts of suspension systems common to most types are axles, springs or torsion bars, shock absorbers, bogies, wheels, and tracks. Since springs, torsion bars, and shock absorbers are used on both wheeled and tracklaying vehicles, they are described in *a* through *g* below. Other components will be discussed under the systems in which they are used.

a. Springs.

(1) *Laminated leaf springs.* Laminated leaf springs (fig. 409) are commonly used on

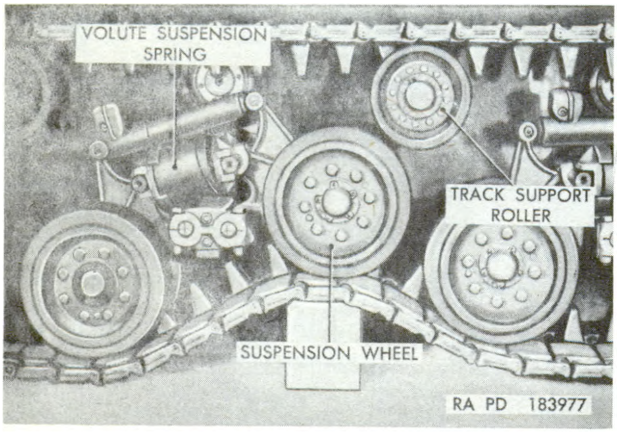


Figure 407. Horizontal volute spring suspension.

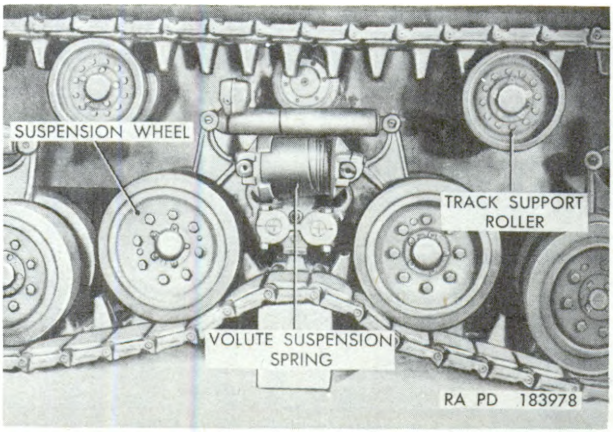


Figure 408. Horizontal volute spring suspension.

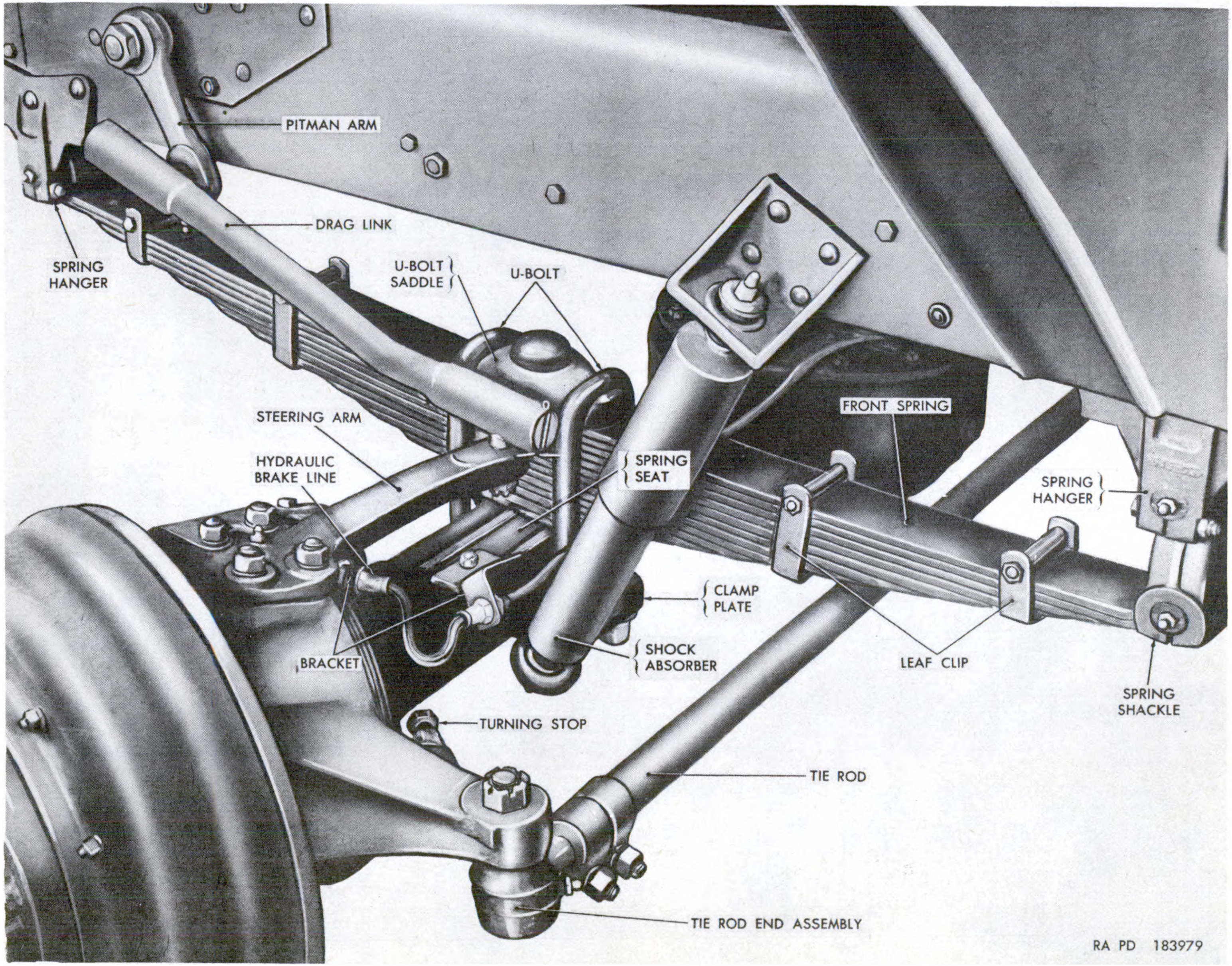

PITMAN ARM
DRAG LINK
SPRING HANGER
U-BOLT SADDLE
U-BOLT
STEERING ARM
HYDRAULIC BRAKE LINE
SPRING SEAT
FRONT SPRING
SPRING HANGER
CLAMP PLATE
SHOCK ABSORBER
BRACKET
LEAF CLIP
SPRING SHACKLE
TURNING STOP
TIE ROD
TIE ROD END ASSEMBLY
RA PD 183979

Figure 409. Front axle leaf spring and shock absorber.

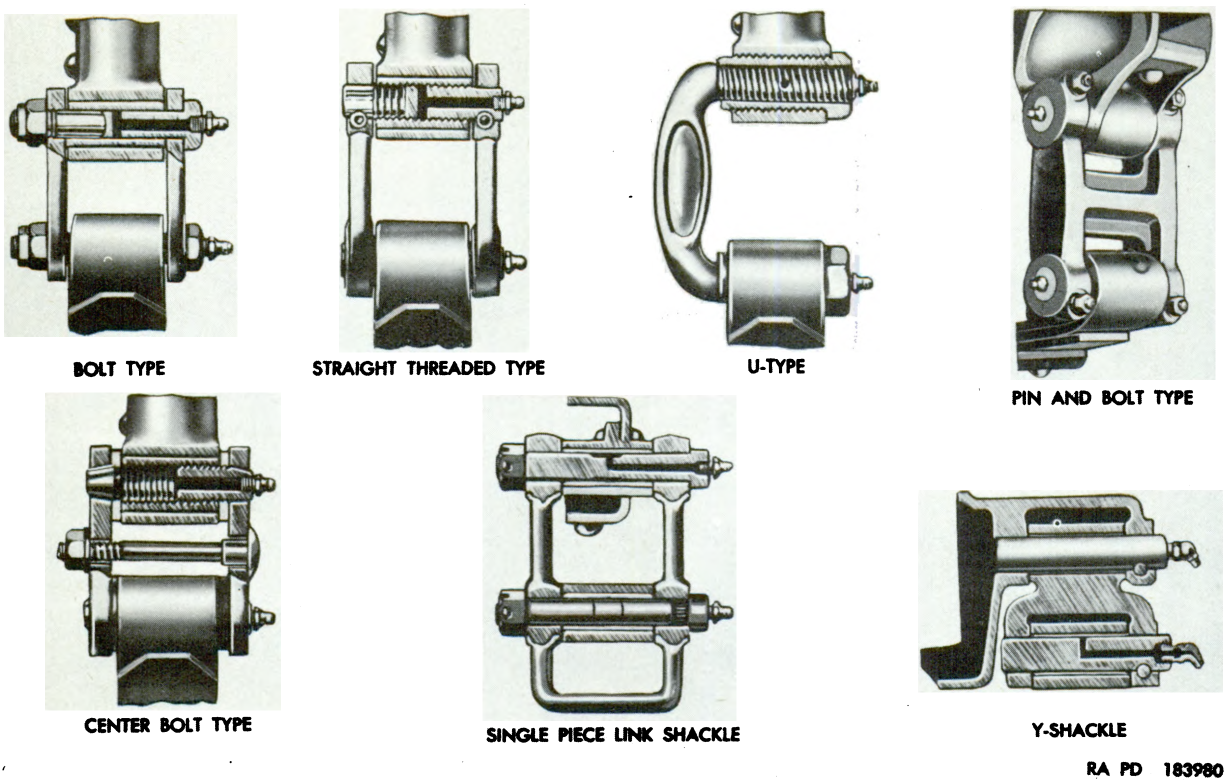


Figure 410. Spring shackles of various types.

trucks and other wheeled vehicles. One end of the spring is attached to the vehicle frame by a short shackle (fig. 410).

(2) *Coil springs* (fig. 411). These springs have the widest application because they are less costly to manufacture, they are compact, and they are efficient. The main disadvantage is that excessive pitching of the vehicle results from their frictionless action, and shock absorbers must be used if pitching is to be eliminated.

(3) *Rubber springs.* Experimental use of rubber springs on light vehicles has been underway for some time, but, until more information is obtained, it is not known whether their use will become general. In this system the elasticity of rubber is utilized in the same manner as the elasticity of steel is used in torsion bars. Rubber is inserted between a bushing in the frame and a bushing in a lever arm connected to the axle, and is bonded to both metal surfaces. As weight is increased or roughness in the road is encountered, the lever arm tends to turn in the frame, but the turning is resisted by the rubber.

(4) *Volute springs.* These are helical coil springs made from flat steel, tapered both in width and thickness, instead of steel wire. Each coil overlaps the adjacent coil, with the widest and thickest part having the greatest diameter. The greater the pressure placed on the spring, the more resistance the spring offers, because the heavier portion of the spring is brought into play. This characteristic protects the spring from overload, but tends to lower the endurance because of the unfavorable stresses created. The vertical type is shown in figure 412, and the horizontal type in figures 407 and 408. This type of spring is desirable when heavy loads must be supported, and when space limitations prohibit use of conventional helical or laminated leaf springs.

b. Torsion Bar. This device consists of a steel rod, serrated on each end attached to the torsion bar anchor at one end and to the road wheel arm

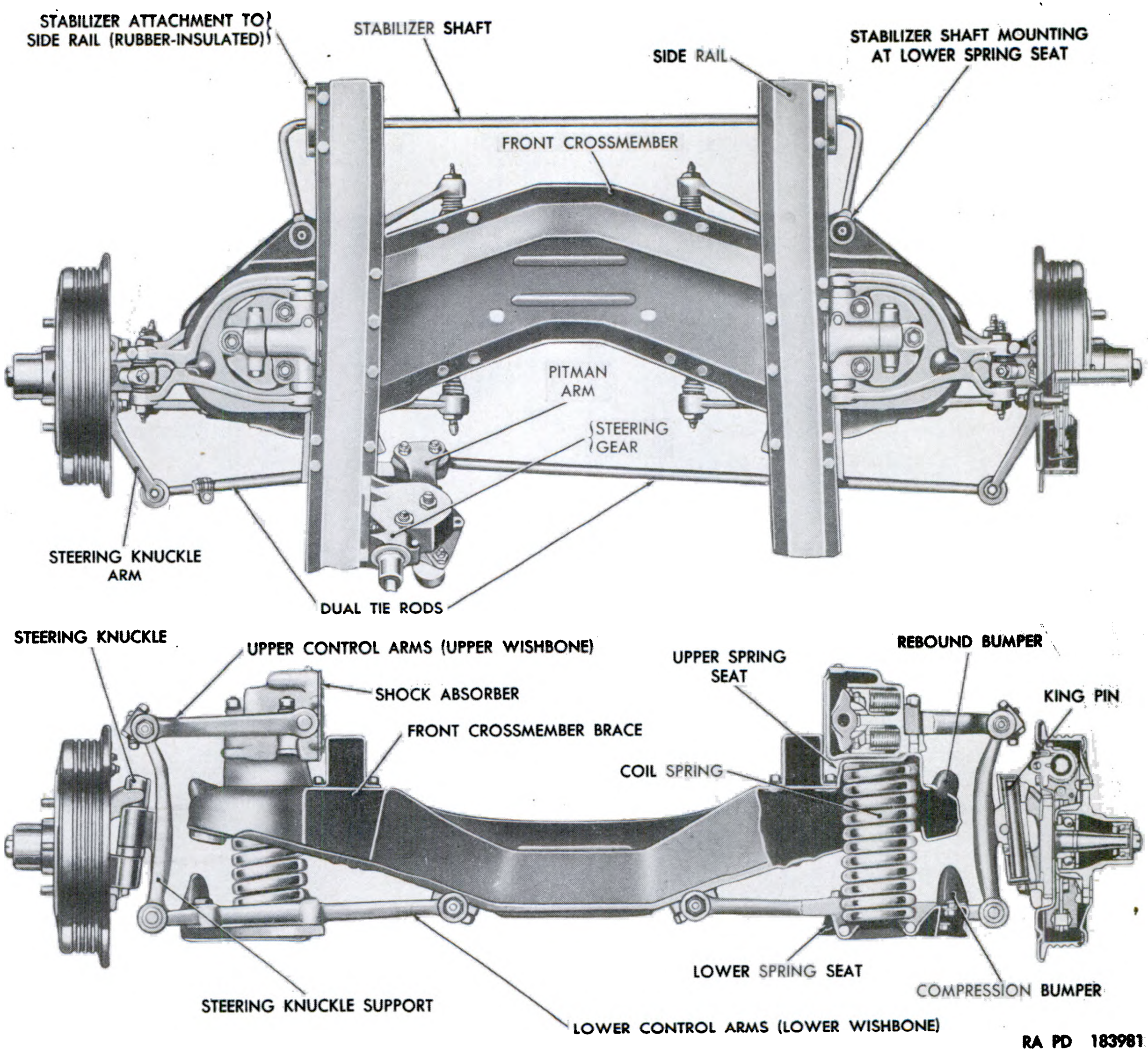

STABILIZER ATTACHMENT TO SIDE RAIL (RUBBER-INSULATED)
STABILIZER SHAFT
SIDE RAIL
STABILIZER SHAFT MOUNTING AT LOWER SPRING SEAT
FRONT CROSSMEMBER
PITMAN ARM
STEERING GEAR
STEERING KNUCKLE ARM
DUAL TIE RODS
STEERING KNUCKLE
UPPER CONTROL ARMS (UPPER WISHBONE)
SHOCK ABSORBER
FRONT CROSSMEMBER BRACE
UPPER SPRING SEAT
REBOUND BUMPER
KING PIN
COIL SPRING
LOWER SPRING SEAT
COMPRESSION BUMPER
STEERING KNUCKLE SUPPORT
LOWER CONTROL ARMS (LOWER WISHBONE)
RA PD 183981

Figure 411. Front-axle coil spring suspension.

at the other, usually through a crank-shaped unit (fig. 413). The elasticity of the rod is utilized, and as long as the elastic limit is not exceeded, the torque resistance will return the road wheel to normal position in the same manner as a spring arrangement. The torsion bars located inside the hull of the vehicle are better protected from enemy fire, but their manufacture is more difficult and adjustment is more complicated. Torsion bars are marked to indicate proper installation by an arrow stamped into the metal, and it is essential that they be installed properly since they are designed to take stress in one direction only.

c. *Shock Absorbers.*

(1) The main function of a shock absorber is to regulate the spring rebound so that the spring returns to rest slowly, thus, preventing sudden jolts and bounces from being transmitted to the vehicle body and its occupants and cargo. Shock absorbers which check only the spring rebound are known as *single-acting*.

(2) A shock absorber may also dampen the compression of the spring by absorbing part of the energy as the spring is depressed. Shock absorbers which check

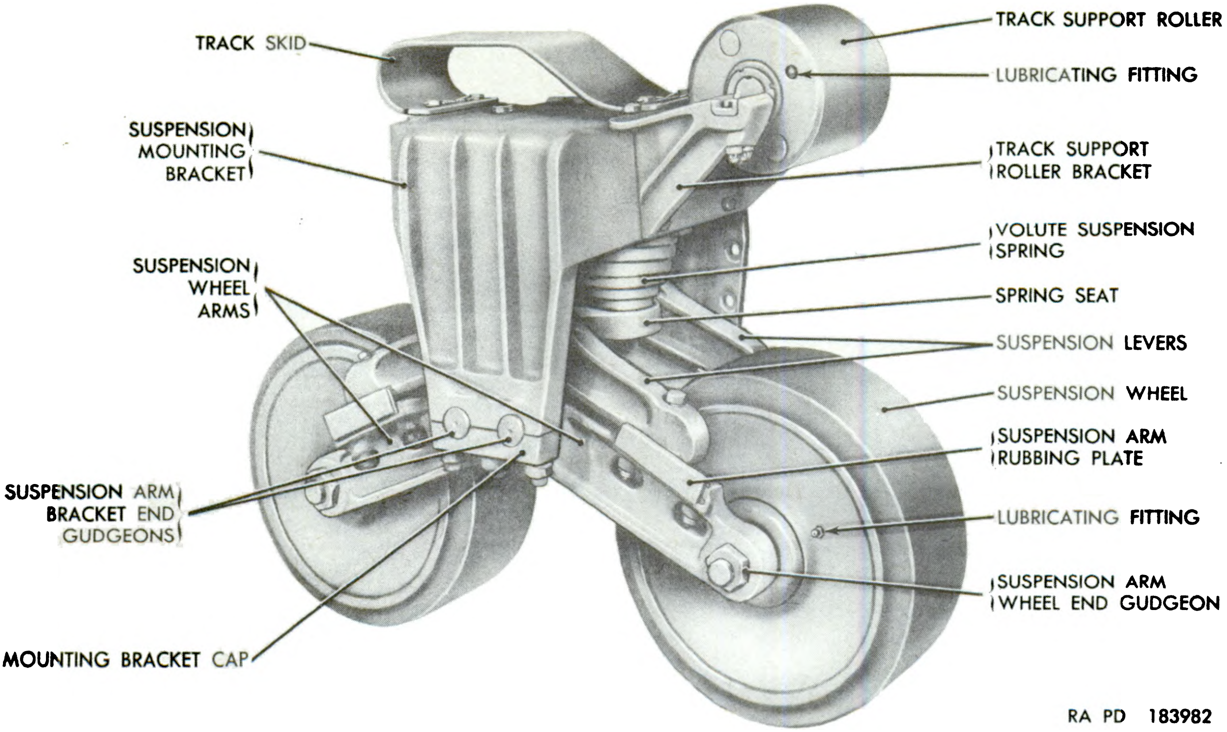

TRACK SKID
SUSPENSION MOUNTING BRACKET
SUSPENSION WHEEL ARMS
SUSPENSION ARM BRACKET END GUDGEONS
MOUNTING BRACKET CAP
TRACK SUPPORT ROLLER
LUBRICATING FITTING
TRACK SUPPORT ROLLER BRACKET
VOLUTE SUSPENSION SPRING
SPRING SEAT
SUSPENSION LEVERS
SUSPENSION WHEEL
SUSPENSION ARM RUBBING PLATE
LUBRICATING FITTING
SUSPENSION ARM WHEEL END GUDGEON
RA PD 183982

Figure 412. Vertical volute spring suspension.

compression in addition to rebound are known as *double-acting.* Most shock absorbers used at the present time are double-acting type, because they permit the use of more flexible springs.

a. Shock Absorber Operation.

(1) There are many types of shock absorbers. Some that have been used operate by friction and spring tension. Those used at present are hydraulically operated and depend upon the resistance of a liquid flowing through a restricted opening to dissipate the energy of the spring.

(2) The principle of the hydraulic shock absorber is rather simple. Oil contained within a housing is forced through a restricted opening by a piston when the vehicle spring flexes. Since liquids are not compressible under ordinary pressures, the oil takes a certain time to flow through the restricted opening. The rate of piston travel, which controls the period of spring vibration, is determined by the opening through which the oil must flow. The energy of the road shocks imposed on the spring is dissipated by a shock absorber in forcing the oil through the opening.

(3) The shock absorber generally is attached to the frame of the vehicle in the manner shown in figure 409. Most shock absorbers contain a lever pivoted to a shaft in the housing. This lever is pinned to a link, the other end of which is usually attached to the spring seat or spring clip. Rubber grommets are used at either end of the link to prevent metal-to-metal contact. With independent suspension, the shock absorber lever is often used as the upper control arm (fig. 411) of the spring mounting.

(4) In the more common type of shock absorbers, the lever, which is moved by spring action, operates a cam that actuates the piston. In some types the lever operates a vane which acts as a piston. On one type shock absorber widely used on passenger cars the piston is directly operated by spring action.

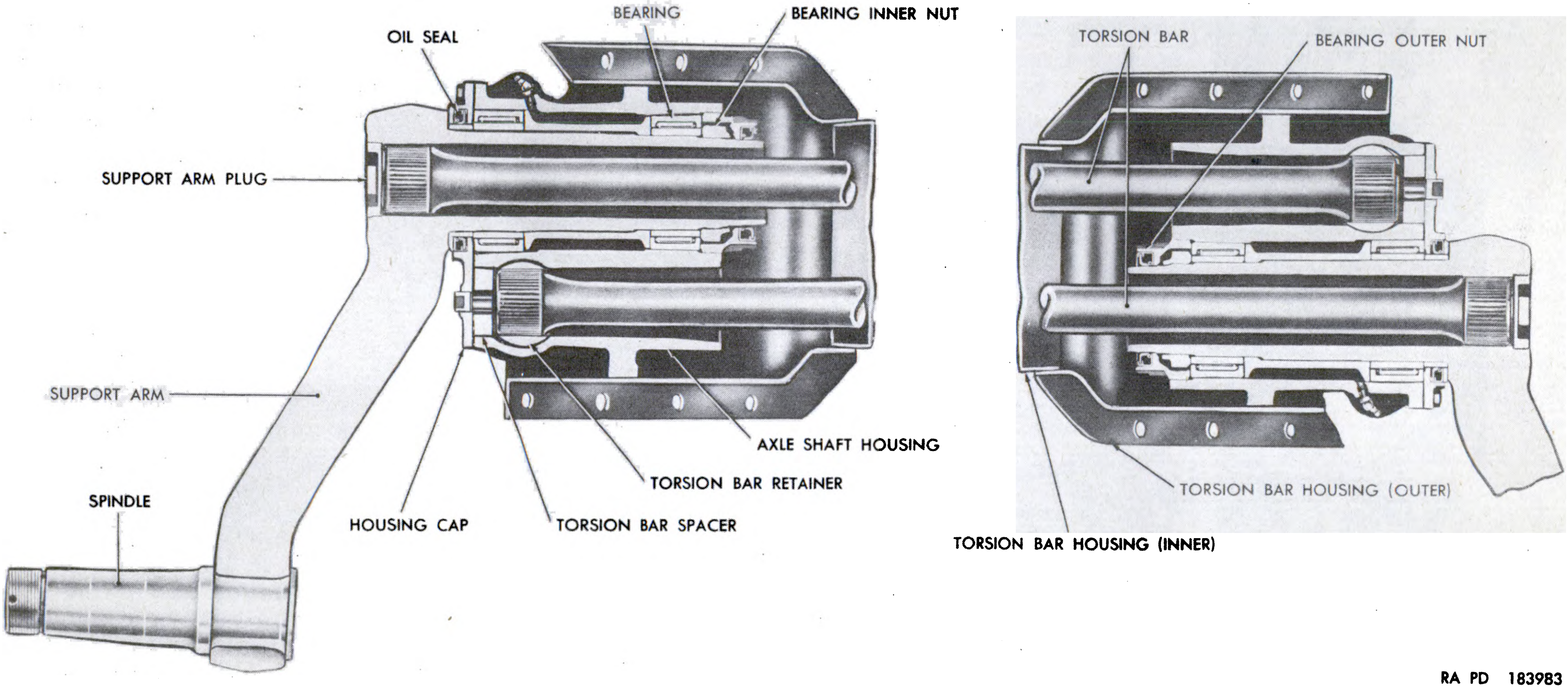

BEARING
BEARING INNER NUT
OIL SEAL
SUPPORT ARM PLUG
SUPPORT ARM
SPINDLE
HOUSING CAP
TORSION BAR SPACER
TORSION BAR RETAINER
AXLE SHAFT HOUSING
TORSION BAR
BEARING OUTER NUT
TORSION BAR HOUSING (OUTER)
TORSION BAR HOUSING (INNER)
RA PD 183983

Figure 413. Torsion bars, track wheel support arm, and spindle—cross sectional view.

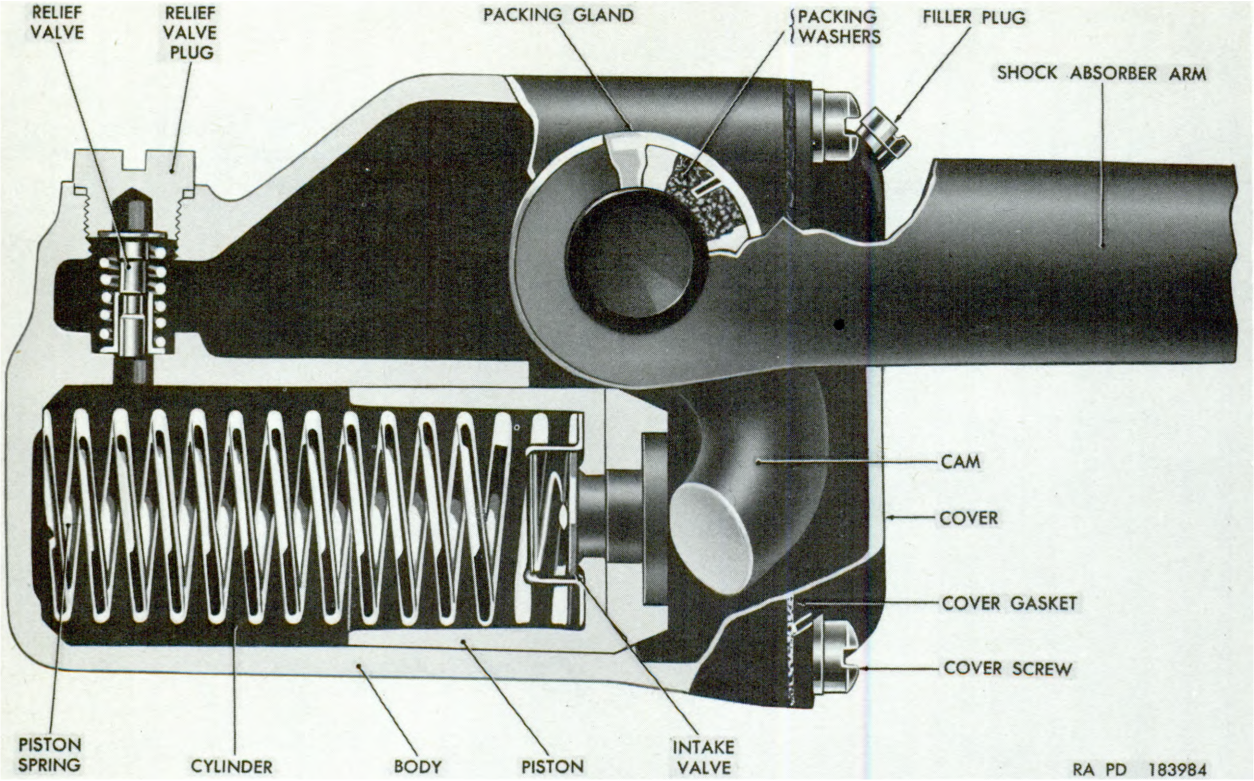


Figure 414. Single-acting shock absorber (cam-operated piston).

e. Cam Shock Absorbers.

(1) *Single-acting.*

(*a*) A cam-operated shock absorber designed to check the rebound only is shown in figure 414. The housing, or body, contains an oil-filled reservoir and an inner cylinder. Within the cylinder is a piston operated by a cam mounted on the shaft to which the arm is mounted. The piston is held against the cam by a coil spring in the cylinder. Inside the piston is an intake or check valve which permits oil to enter the cylinder from the outer reservoir. The cam moves to the right when the vehicle spring is compressed. The piston spring forces the piston to follow the cam, opening the intake valve and allowing oil to flow into the cylinder. This valve has a large port opening so that it offers little resistance to the flow of oil and therefore has little effect upon the action of the vehicle spring.

(*b*) When the vehicle spring rebounds, the cam is moved in the reverse direction and forces the piston to the left against the oil in the cylinder, closing the intake valve. The motion of the piston forces the oil confined in the cylinder through the relief valve to the outer reservoir. The escape of oil through this valve is controlled and regulated by the size of the opening and by the valve spring pressure holding the valve against its seat. The instant the vehicle spring stops its rebound the relief valve is closed by its valve spring. The valves shown in figure 414 may have an entirely different construction and arrangement than the type shown. The relief valve is sometimes included in the piston along with the inlet valve.

(2) *Double-acting.*

(*a*) The operating principle of the double-acting shock absorber is the same as the single-acting shock absorber except that it provides a damping action in

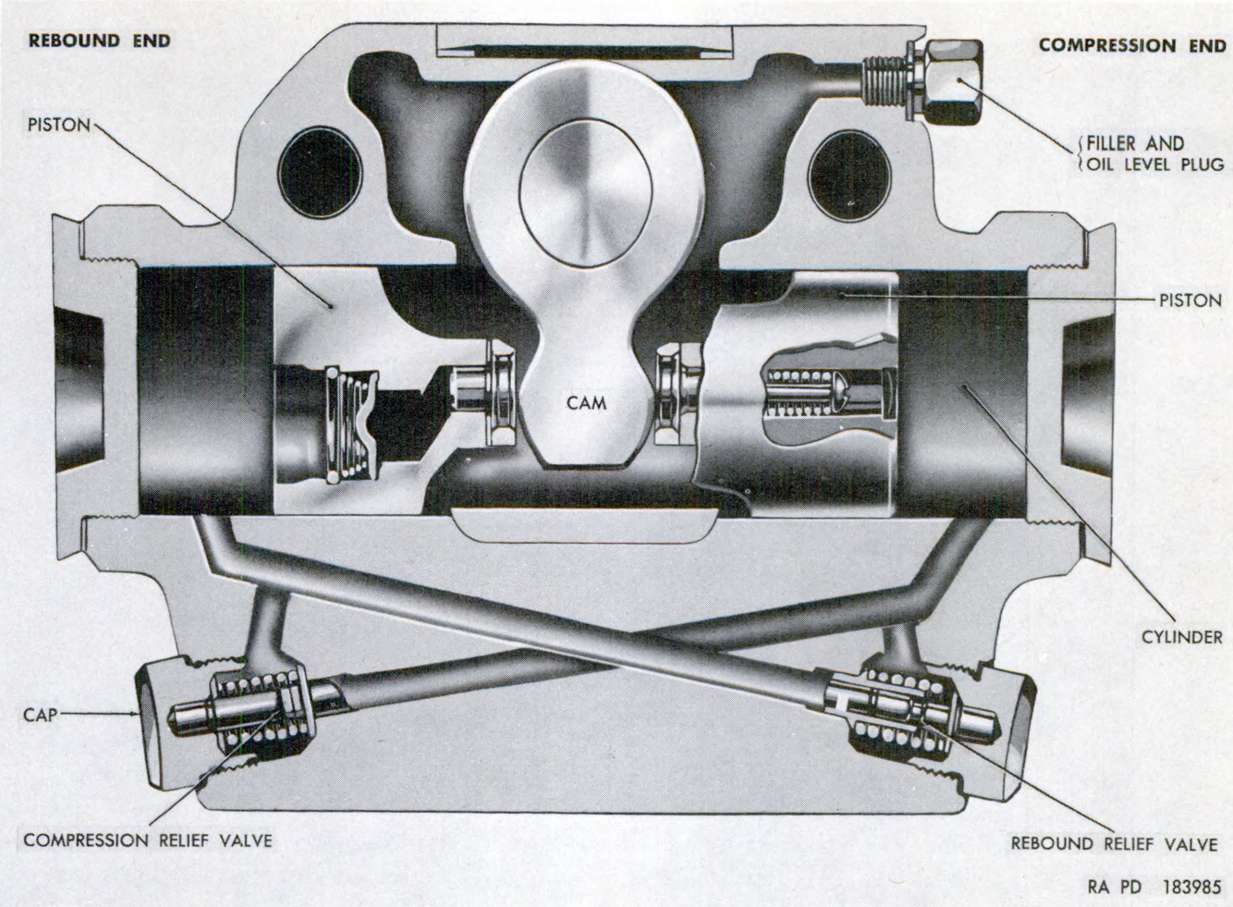


Figure 415. Opposed-cylinder, double-acting shock absorber (cam-operated piston).

both directions. One type of double-acting shock absorber operated by a cam is shown in figure 415. The housing contains an oil reservoir and two cylinders. The cam is inserted between two interconnected pistons, each contained within a cylinder. The double-acting pistons may operate in opposed cylinders made from one bore, as shown in figure 415, or in side-by-side cylinders with a double-arm cam.

(*b*) As the cam moves, due to the action of the vehicle spring, it carries both pistons with it as indicated by the arrows in figures 416 and 417. Each piston has a valve inside to check the flow of oil from the reservoir to either chamber as the pistons move. The shock absorber illustrated has the intake and relief valves for the compression cylinder contained within the compression piston, but only the intake valve for the rebound cylinder is in the rebound piston. The rebound relief valve is in a separate passage leading from the end of the rebound cylinder to the central reservoir. This permits better control of the flow of oil through the relief valve. A separate passage can also be provided for the compression relief valve. The combination of valves used does not affect the operation, although better control may be obtained by separate valves.

(*c*) When the vehicle spring is compressed, the cam forces the compression piston to the left into the compression cylinder. The pressure exerted on the oil in the compression cylinder opens the compression relief valve (fig. 416) and

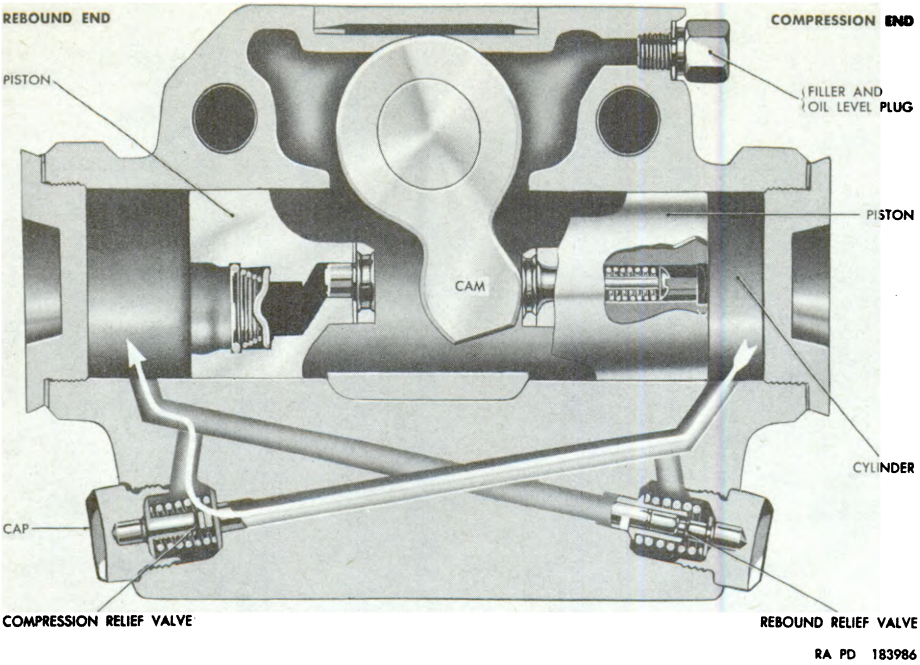


Figure 416. Double-acting shock absorber—action during spring compression.

oil slowly passes through it to the reservoir. The amount of valve opening controls to some degree the compression of the vehicle spring. While the compression side of the shock absorber is operating, the rebound piston is carried with the cam and the rebound intake valve opens to admit oil from the reservoir into the rebound cylinder.

(*d*) As the vehicle springs rebound, the cam carries both pistons to the right as shown by the arrows in figure 417. The oil in the rebound cylinder flows down the passage through the rebound relief valve to the reservoir. The rebound of the vehicle spring is controlled by the size of the valve opening that the oil must flow through. Oil is supplied at the same time from the reservoir to the compression cylinder through the compression intake valve.

(*e*) Some shock absorbers contain a device to vary the dampening effect of the vehicle springs. The speed of compression, or rebound can be varied by providing an additional relief valve whose opening can be controlled either manually or by an inertia weight. A manually controlled valve can be operated from the instrument panel through a linkage. A valve controlled by an inertia weight will automatically control the rebound of the vehicle spring. On smooth roads, the additional relief valve is held open by the inertia weight which is suspended by a spring. The oil then flows through both relief valves when the spring rebounds. When the vehicle spring receives a severe shock, the resulting rebound will be so sudden that the inertia weight will lag, closing the additional relief valve momentarily. All the oil will be forced through the main rebound relief valve in the piston, and the dampening of the spring action will be increased automatically.

f. Vane Shock Absorber.

(1) In a vane shock absorber (fig. 418), the oil is forced through restricted openings by vanes which act as pistons. A cylindrical housing filled with oil is divided into two working chambers by stationary partitions. A vane contained on a central shaft which is operated by the shock absorber lever extends into each working chamber. The vanes oscillate with the vehicle spring and act as pistons.

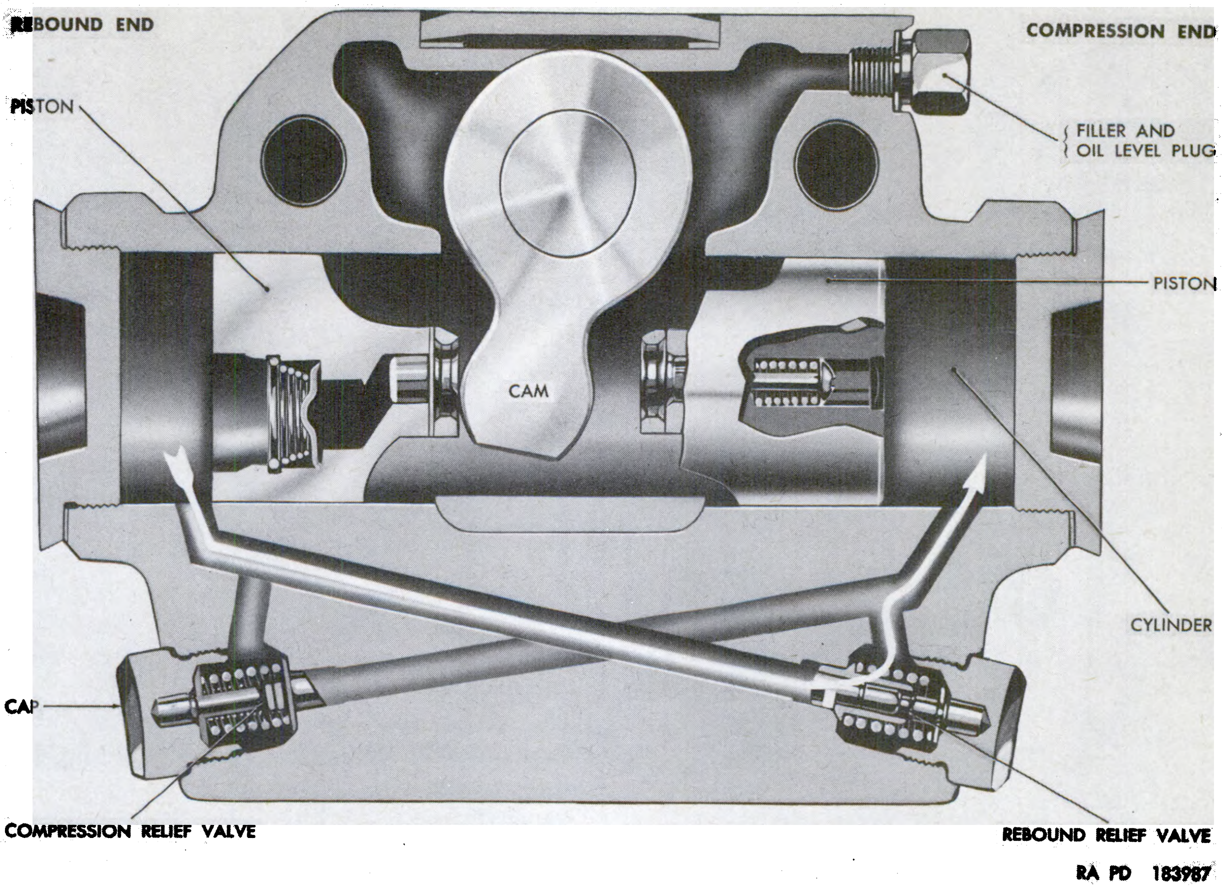

REBOUND END
COMPRESSION END
PISTON
FILLER AND OIL LEVEL PLUG
PISTON
CAM
CYLINDER
CAP
COMPRESSION RELIEF VALVE
REBOUND RELIEF VALVE
RA PD 183987

Figure 417. Double-acting shock absorber—action during spring rebound.

(2) A check valve in each partition permits the liquid to flow through the partitions when the vanes are moved by the compression of the vehicle spring. On the rebound stroke, the vanes move in the opposite direction and exert pressure on the oil, forcing the check valves to close so that the oil has to return to the other side of both partitions through a needle relief valve in the center of the shaft. A manual adjustment is usually provided to change the position of the needle which controls the size of the relief valve opening, and thereby regulates the resistance on the rebound strokes. In another type of vane shock absorber, the relief valve is contained in the stationary partition. A bypass cut in the wall of the housing at the normal position of the vane (corresponding to the stationary position of vehicle spring) allows the fluid to pass by the vanes and offers little resistance to spring action on gentle bumps.

(3) To get maximum performance, the working chambers must be completely filled with liquid and free from dirt so that the

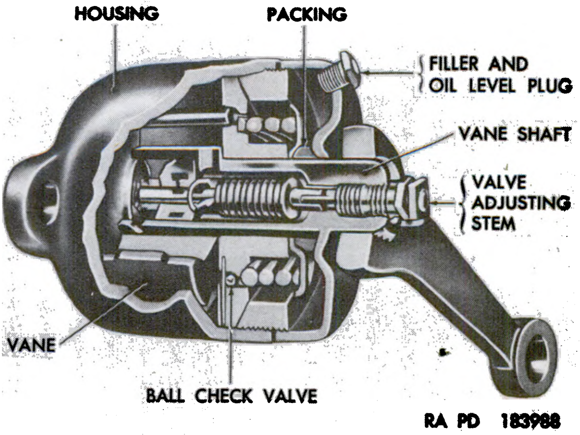

HOUSING
PACKING
FILLER AND OIL LEVEL PLUG
VANE SHAFT
VALVE ADJUSTING STEM
VANE
BALL CHECK VALVE
RA PD 183988

Figure 418. Double-acting vane shock absorber.

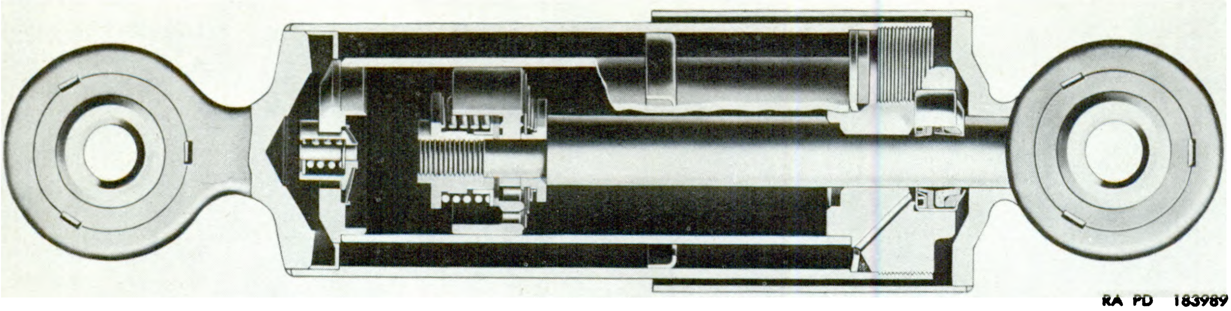

RA PD 183989

Figure 419. Direct-acting shock absorber.

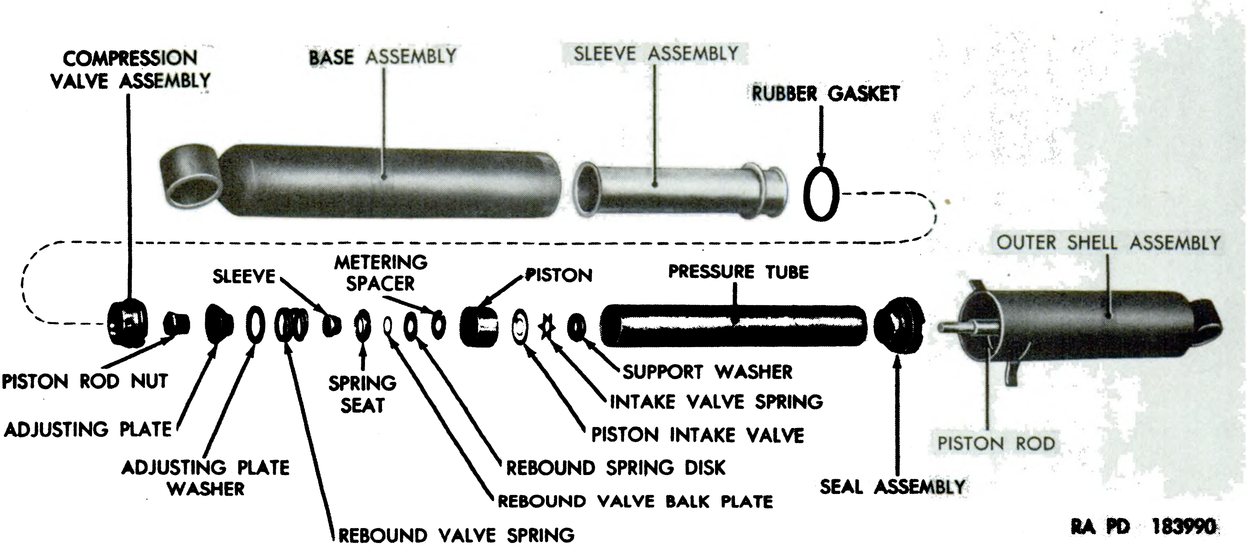

COMPRESSION VALVE ASSEMBLY
BASE ASSEMBLY
SLEEVE ASSEMBLY
RUBBER GASKET
OUTER SHELL ASSEMBLY
SLEEVE
METERING SPACER
PISTON
PRESSURE TUBE
PISTON ROD NUT
ADJUSTING PLATE
ADJUSTING PLATE WASHER
REBOUND VALVE SPRING
SPRING SEAT
SUPPORT WASHER
INTAKE VALVE SPRING
PISTON INTAKE VALVE
REBOUND SPRING DISK
REBOUND VALVE BALK PLATE
SEAL ASSEMBLY
PISTON ROD
RA PD 183990

Figure 420. Direct-acting shock absorber—disassembled view.

valves can open and close freely. Replenishing valves at the bottom of the housing allow oil to flow to the working chambers from a reservoir separated from the working chambers by a partition. These valves close when the liquid in the working chamber is under compression.

g. Direct-Acting Shock Absorber.

(1) The direct-acting shock absorber (figs. 419 and 420) consists of an inner cylinder, filled with a special shock absorber oil, divided into an upper and lower chamber by a double-acting piston. The shock absorber is mounted by studs and rubber bushings inserted through the eye on each end so that it is directly acted upon by spring action. The piston push rod is therefore forced up and down within the inner cylinder. A reservoir which contains an ample supply of oil surrounds the inner cylinder and is joined to it by a reservoir check valve.

(2) When the vehicle spring is compressed, the piston is forced down, and some of the oil below the piston is forced through compression valves (only one is illustrated fig. 420) inside the piston into the upper chamber. These valves operate only on the down stroke. Since the push rod moves into the cylinder on the down stroke, some of the oil in the lower chamber is forced through the reservoir check valve at the bottom of the cylinder into the reservoir.

(3) When the vehicle spring rebounds, the piston is moved up, and oil from the upper chamber is forced into the lower chamber through spring-loaded rebound

valves inside the piston. These valves control the rebound of the vehicle spring. As the piston moves out of the cylinder, oil is drawn into the lower chamber from the reservoir through the reservoir check valve.

(4) An outer metal cover protects the shock absorber from damage by stones, etc., that are kicked up by the wheels. Rubber bushings are fitted on both sides of the eye to prevent metal-to-metal contact with the mounting stud or bolt.

(5) Shock absorbers require little care and attention except to see that the reservoir is kept filled to the proper level with the proper fluid.

Section II. WHEELED VEHICLE SUSPENSION SYSTEMS

236. General

a. The wheels of a vehicle are either mounted on a spring-suspended axle or suspended independently on springs. Driving wheels are mounted on a live driving axle that is suspended by springs attached to the axle housing. Four types of attachment are shown in figure 286. Laminated leaf springs are usually used for suspending live axles, although coil springs are used on a number of passenger cars with torque arm or torque-tube drive.

b. The front wheels of rear-drive motor vehicles were, until recently, nearly always mounted on a dead axle. Dead front axles are still used on a few passenger cars, however, and are extensively used on trucks and other heavy vehicles. The development of satisfactory independent suspension systems did away with front axles on most passenger cars. A live front axle which acts as a driving member is used in front- or all-wheel drive designs. The construction and suspension of the front axle are then similar to the conventional rear axle except for the provision for steering.

237. Dead Axles

a. General. The front axle of some conventional motor vehicles is a dead axle. To permit steering the front wheels of a motor vehicle, the front axle is made of three sections joined together.

b. Requirements. Dead axles must be able to support the weight of the vehicle and also be able to resist the stresses that occur when the brakes are applied. They must have sufficient stability to keep the wheels in proper alinement so that the vehicle holds its course.

c. Construction. Dead axles are generally made of I-section, drop-forged from medium carbon or alloy steel and heat treated to give them toughness and strength. The more expensive tubular section made from molybdenum steel is often used to reduce unsprung weight and give the axle resistance against high braking torque. As little road clearance is required, the center of the axle is usually dropped in passenger vehicles so that the vehicle weight can be lowered. A straight axle is generally used for trucks. Dead axles are suspended by laminated leaf or coil springs. The springs are held on the axle by spring seats and are attached by **U**-bolt clips (fig. 409) or some similar method.

238. Independent Suspensions

a. Purpose. If one of the two wheels mounted at opposite ends of a rigid axle receives a jar or jolt, the whole suspension system, including the axle, is affected. This means that a large unsprung weight is set in motion, which results in poor riding qualities. When a wheel hits an obstruction, the force of impact is directly proportional to the unsprung weight carried by it. This force of impact strains the wheels, axles, springs, steering mechanism, etc., and it also has a destructive effect on the road. Hence, it is highly desirable to reduce the unsprung weight as much as possible. With independent suspension (fig. 411), the wheels of a motor vehicle are individually supported so that each will function independently of the others. Either the front or rear wheels, or both, may be independently suspended.

b. Advantages. The following are the most important advantages of independent suspension. When one wheel passes over an obstruction, the shock is not transmitted to the opposite wheel, thereby aiding steering and reducing chassis distortion; the unsprung weight, reduced to a minimum, is confined to the weight of the wheel itself and does not include the axle, springs and steering linkage, thereby improving riding qualities.

239. Heavy Vehicle Suspension

a. Springs. Several methods of spring suspension have been used for vehicles which carry

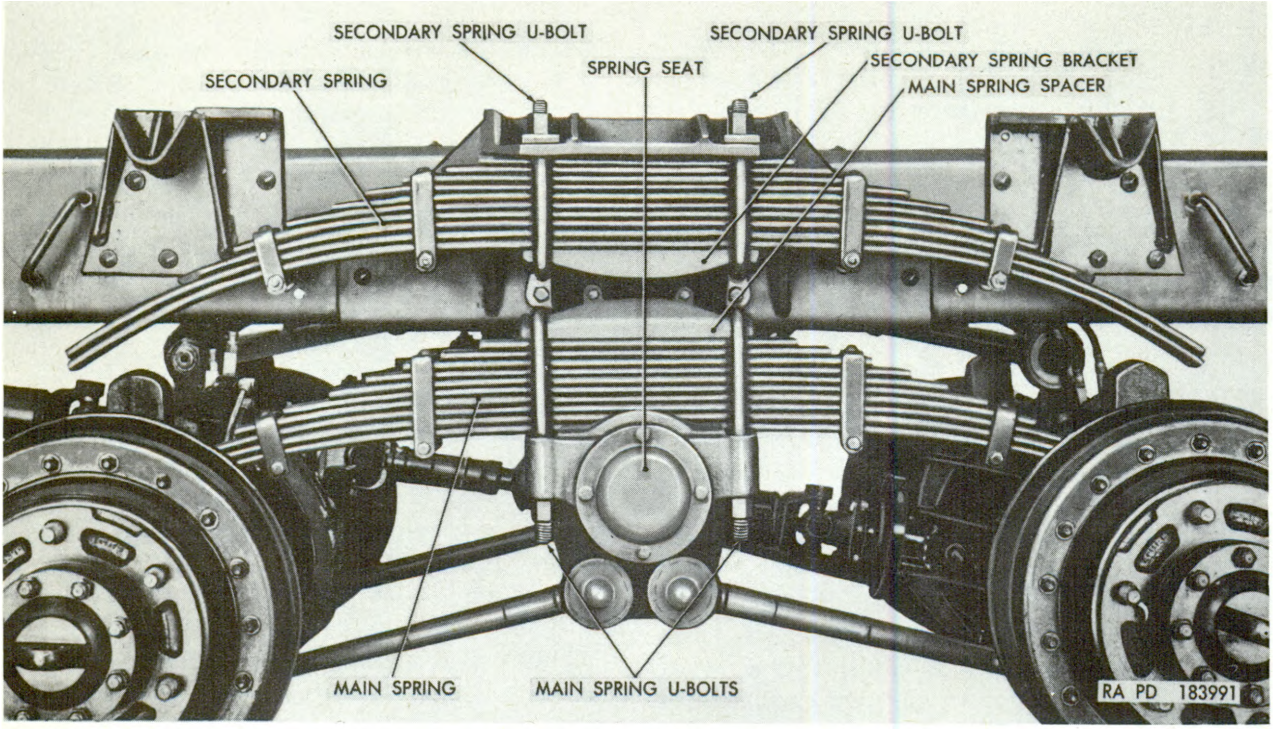


Figure 421. Auxiliary spring suspension.

widely varying loads in order to increase the load rating of the spring suspension as the load increases.

(1) Auxiliary springs, often called secondary springs (fig. 421), are commonly used in addition to the mainspring to accomplish this purpose. When the load on the spring reaches a certain amount, the deflection of the mainspring brings the free ends of the secondary spring against bearing plates on the frame, or on the axle if the secondary spring is secured to the frame. From that point on, the two springs carry the load jointly and their load ratings are added. This enables the vehicle to carry heavy loads without unduly deflecting the mainsprings.

(2) Another method of suspension that also provides a spring with variable-load rating is shown in figure 422. The spring is made with flat ends which bear against curved bearing plates. With a light load, the springs make contact with the outer edges of the bearing plates; hence, the effective length of the spring is comparatively large and it has a low load rating. Heavy loads deflect the spring, causing the points of contact to move toward the inner edges of the bearing plates. Hence, the effective length of the spring becomes shorter, giving a higher load rating.

b. Axles. Two rear axles are used on numerous heavy vehicles to decrease the load on each rear wheel, to decrease the effect of road shocks, and to increase traction. A typical rear end on 6-wheel vehicles consists of an axle mounted on each end of the rear springs, with the load of the vehicle applied at the center of the spring by means of a spring seat supported on the frame. The drive is applied to the forward of the two axles, with the rear axle trailing, or it is applied to both axles by means of an interaxle differential, insuring equal driving effort on both axles. Torque rods apply the driving force to the frame and are usually arranged to relieve the springs of any torque reaction. The rear springs carry the same load they do with a single rear axle, but the load is distributed over two axles instead of one.

c. Bogie Axles.

(1) A large proportion of 6-wheel vehicles have bogie axles. A bogie is a suspension unit, such as shown in figures 422 and 423, consisting of two axles joined

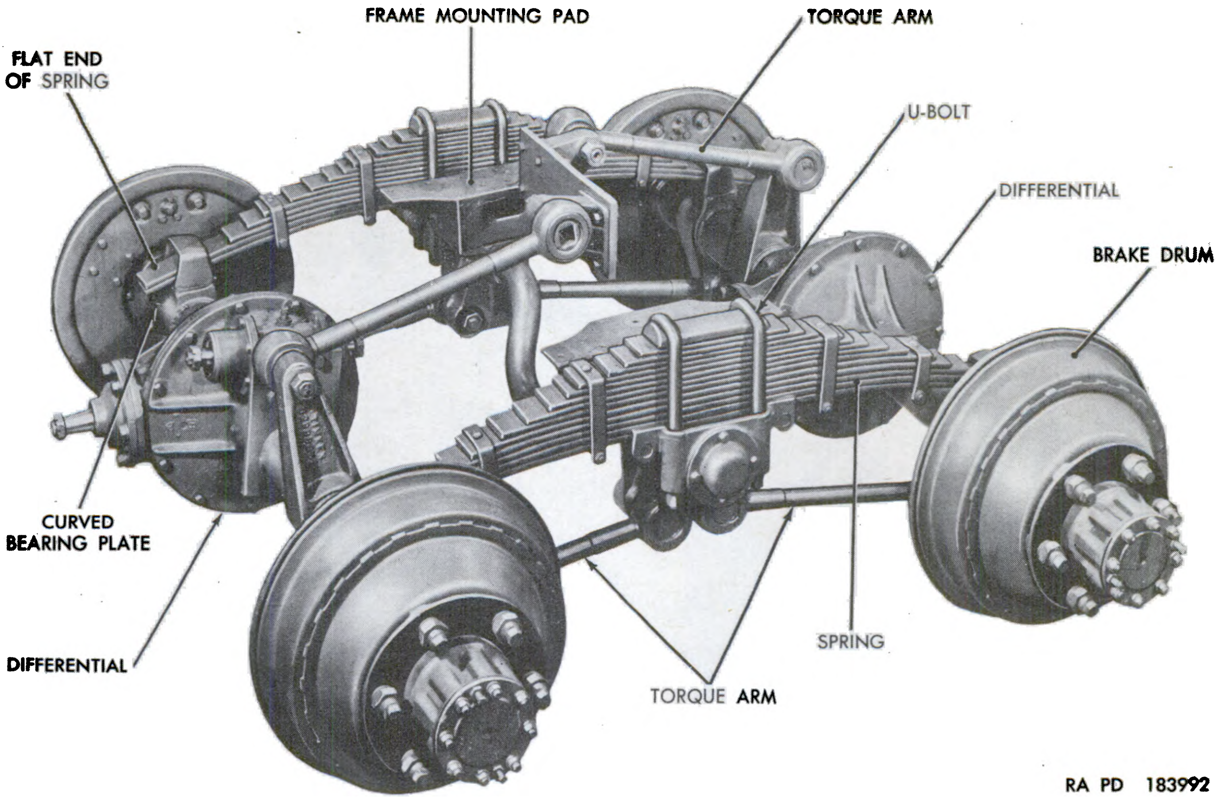


Figure 422. Variable-load spring arrangement.

by a single cross support (trunnion axle) that acts as a pivot for the entire unit. The tubular trunnion axle is rigidly attached to the frame through mounting pads by two support brackets and girder cross member. The ends of each spring rest on hardened steel bearing plates on the two axle housings, the spring being supported on the vehicle frame by means of a spring seat on each end of the trunnion axle. Both springs are clamped on their spring seats by means of spring clips.

(2) Both spring seats are mounted on a spindle on each end of the trunnion axle. Tapered roller bearings take side thrust imposed on the spring and allow it to pivot easily. Springs with very high load rating must be used with this suspension because they carry the entire weight of the rear end. Mounting the springs on central pivots enables them to distribute half of the rear end load to each axle. As a result, the load on the rear of the vehicle is distributed over four wheels, allowing a vehicle to carry much heavier loads than a single rear axle vehicle, without exceeding the safe tire load.

(3) When one wheel is deflected from a road shock, the spring pivots about its center so that both ends of the spring deflect to absorb the energy of the road shock, rather than just one end. Thus, the effect of road shocks is cut in half. When only one axle is deflected up or down from its normal loaded position, the trunnion axle, and the vehicle frame, is raised or lowered half this amount. In this manner, bogie axles reduce by half the impact or shock not only to the vehicle, but also to the road.

240. Auxiliary Units

a. Purpose. Various units are added to the spring-axle-wheel combination to eliminate hazards and to provide longer life for the parts. These will be discussed briefly.

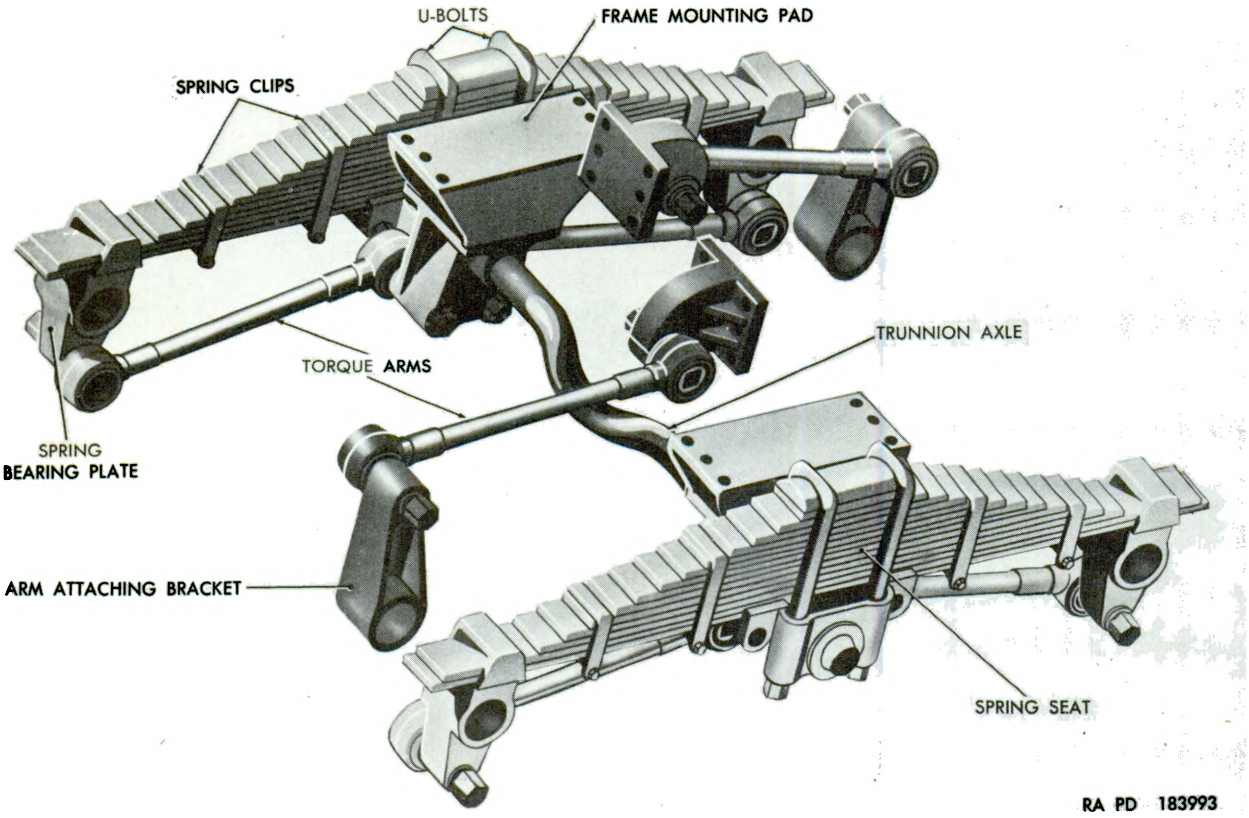


Figure 423. Rear spring installation.

b. Torque Devices. When power and brake effort are applied, there is a tendency for the entire axle and spring assembly to rotate. To prevent this, strengthening arms are added to the axles. These are known as *torque arms*, *torque rods*, and *torque tubes* (fig. 286). The function of these three is the same, the major difference being that the torque tubes connect with the power train, whereas the other two connect with the frame of the vehicle. Parallel torque arms (fig. 423) used between axles in bogie suspensions insure correct spacing and alinement of the axles, prevent transfer of weight from one axle to the other (or the tendency of one axle to "dig in" more than the other), and help to avoid uneven tire wear and "jumping axle" when brakes are applied.

c. Swaybars. A vehicle tends to roll outward when turning, particularly at high speeds. To prevent this roll, swaybars or stabilizers (fig. 411) are used. The swaybar consists of a bar of alloy steel mounted across the chassis and secured to the frame through rubber bushings with arms on each end connected to the axle or independent suspension arms. When one side of the vehicle rises faster than the other, the twist set up in the swaybar reacts on the axle or independent suspension arms, tending to keep the frame level. If both sides rise equally, no twist is set up in the swaybar.

Section III. TRACKLAYING VEHICLE SUSPENSION

241. General

Tracklaying vehicles are designed for the purpose of affording transportation where ordinary cars and trucks cannot travel. The suspension systems, therefore, must perform the same functions as those of wheeled vehicles and, in addition, be able to absorb much greater shock and vibration and have greater flexibility. The tremendous weight of tracklaying vehicles determines the area of the tracks in contact with the ground. As far as is possible, tracks are of such size that the pressure on a square foot of ground is about

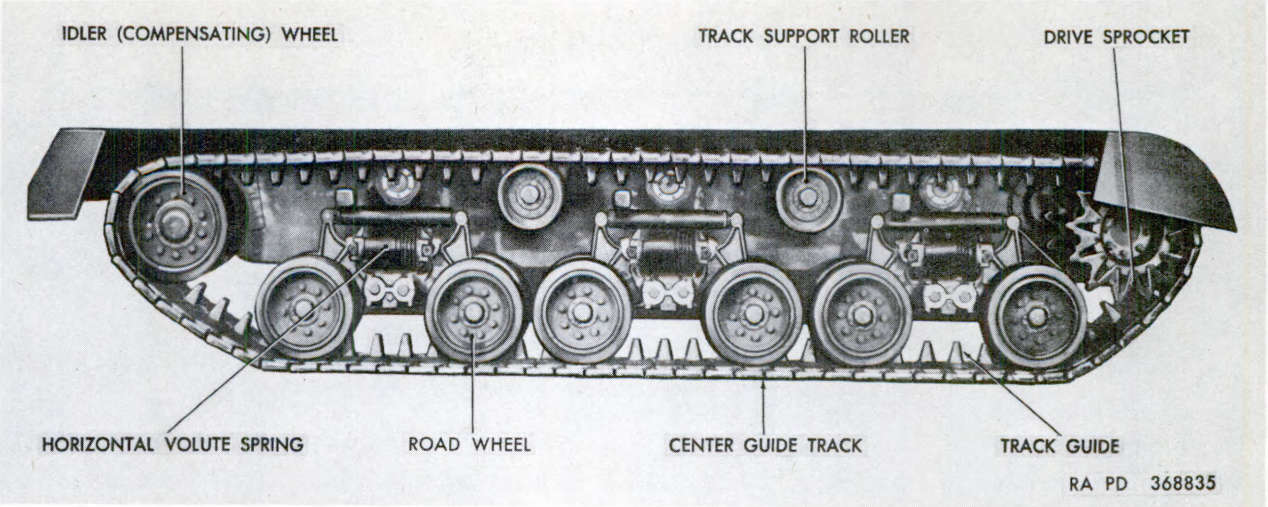


Figure 424. Horizontal volute spring suspension.

equal to that exerted by a man of normal size. To accomplish this amazing distribution of weight and to meet all these requirements, a number of suspension systems have been adopted. Basically, a tracklaying vehicle does just what its name implies; it lays its own road, then picks it up and again lays it. Keeping this in mind, it is easy to see that the suspension system is really the same as that of wheeled vehicles, with added features to meet the additional requirements mentioned.

242. Principal Parts

a. Spring Arrangement. Arrangement of the springs on suspensions has never been entirely satisfactory. Vertical volute springs (fig. 412) cannot be satisfactorily damped. Therefore, horizontal springs (fig. 424), or torsion bars (figs. 425, 426, and 427), are favored for most tracklaying vehicles. In the torsion bar system, spring steel bars, serrated at each end, are used. One end is anchored so it cannot turn, but the other end is rigidly attached to the road-wheel arm. As the track meets irregularities in the road, the road wheel moves up and down, causing the road-wheel arm to pivot about its support. This action causes the torsion bar to twist. The torsion bar acts as a spring, twisting more or less as the road wheel moves up and down.

b. Road Wheels. In modern tracklaying vehicles, road wheels are usually rubber-tired. This affords quieter operation and a great reduction in wear of wheels and tracks.

c. Idler Wheels and Track Supporting Rollers. These are used to keep the track up out of the suspension mechanisms, to guide the track, and to maintain tension (fig. 424).

243. Classification

Systems that have been used may be classified in general groups described in *a* through *b* below.

a. In the single-arm type, each wheel is mounted on a crank-shaped axle with a spring or torsion bar to keep it in place, that is, on the ground.

b. If two wheels are mounted on a bar and that bar is attached to the crank-shaped axle, the system is called a *double-arm type.*

c. If the wheels are mounted on two bars, and the bars have a common pivot which is movable, the system is known as the *double articulated-arm* type. Since the wheels can move independently or together as a unit, this system has the greatest flexibility, and accordingly is one of the most popular.

d. Vertical volute springs (fig. 412) are also used. Systems employing them are known as *vertical suspension systems.*

e. Horizontal volute springs (fig. 424 and 428) are also used. Systems of this type are called *horizontal suspension systems.*

f. Track suspension systems using torsion bars (fig. 425, 426, and 427), are known as *torsion-bar suspension systems.*

g. Articulated bogie systems (fig. 429), are used in some vehicles.

h. A system used on many foreign tracklaying vehicles is the Christie. Full-size wheels are used in place of the small bogie and track-supporting wheels, with a large saving in amount of power required.

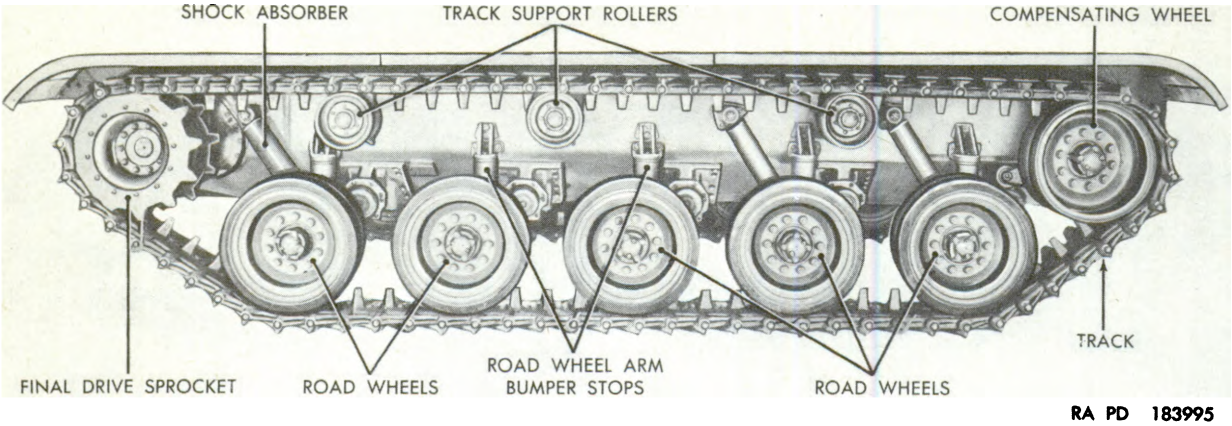

SHOCK ABSORBER
TRACK SUPPORT ROLLERS
COMPENSATING WHEEL
TRACK
FINAL DRIVE SPROCKET
ROAD WHEELS
ROAD WHEEL ARM BUMPER STOPS
ROAD WHEELS
RA PD 183995

Figure 425. Track suspension system using torsion bars.

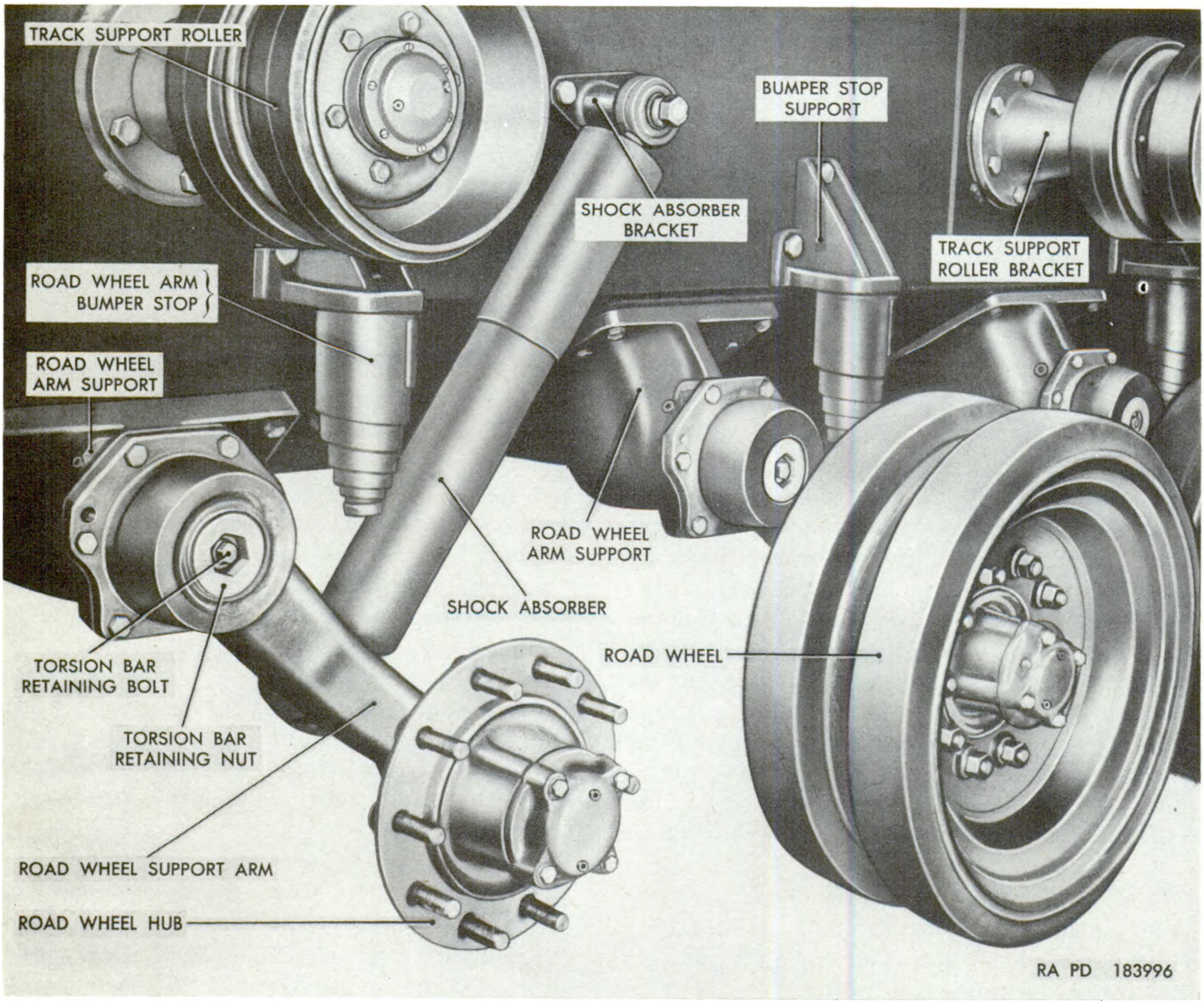
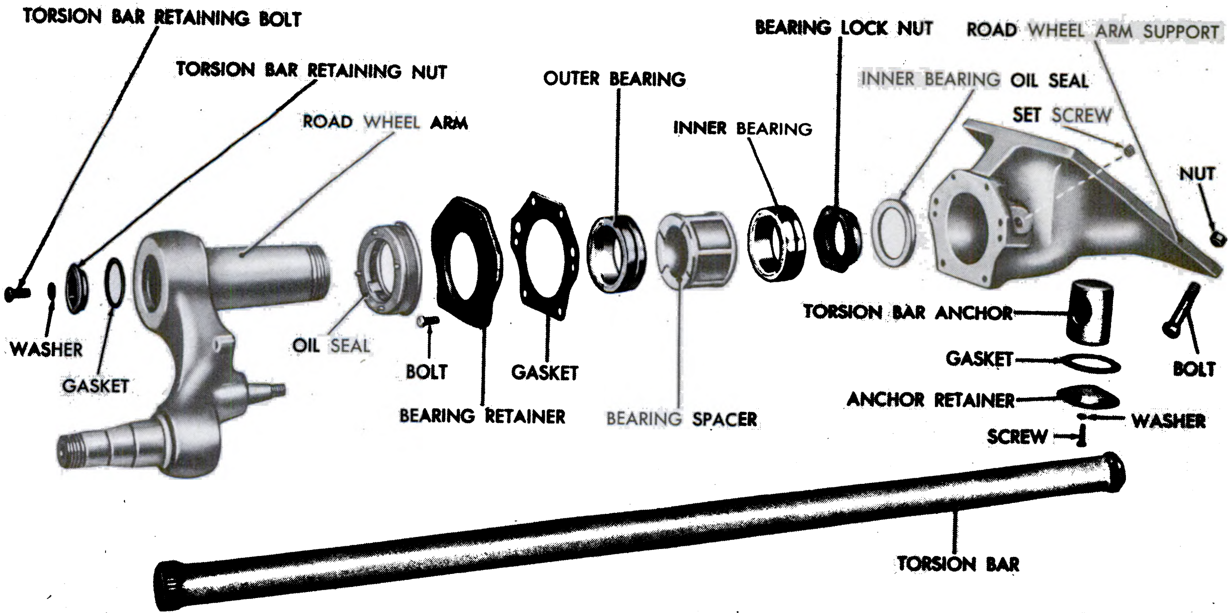
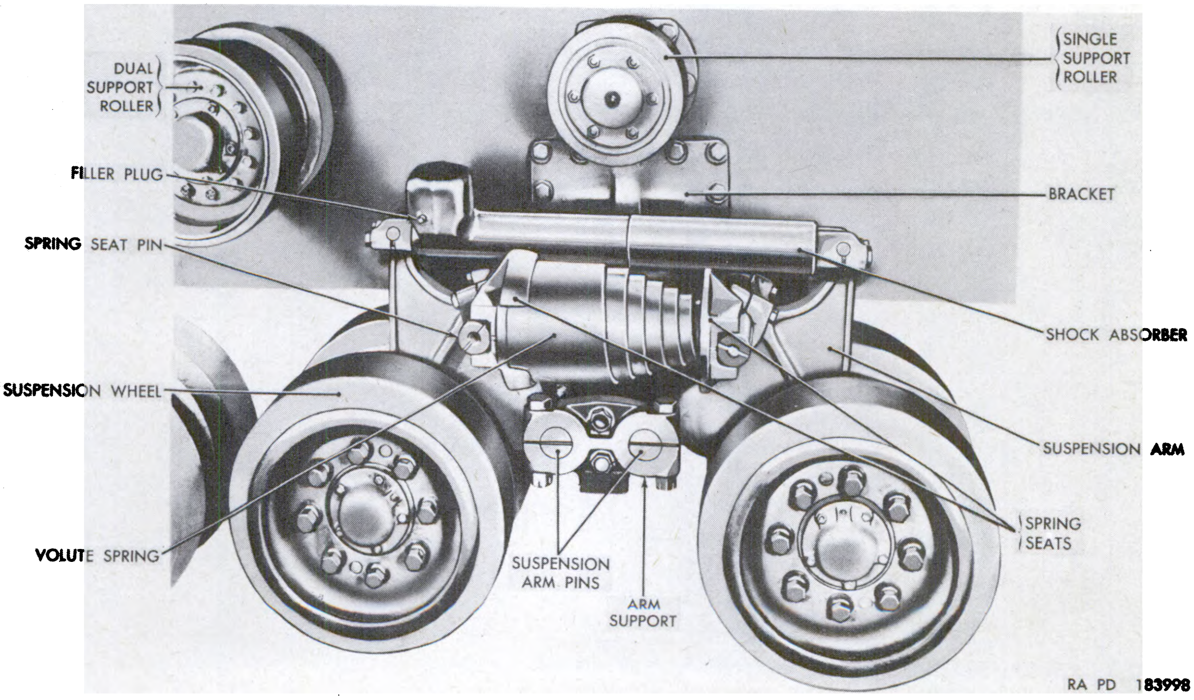

TRACK SUPPORT ROLLER
BUMPER STOP SUPPORT
SHOCK ABSORBER BRACKET
TRACK SUPPORT ROLLER BRACKET
ROAD WHEEL ARM BUMPER STOP
ROAD WHEEL ARM SUPPORT
ROAD WHEEL ARM SUPPORT
SHOCK ABSORBER
ROAD WHEEL
TORSION BAR RETAINING BOLT
TORSION BAR RETAINING NUT
ROAD WHEEL SUPPORT ARM
ROAD WHEEL HUB
RA PD 183996

Figure 426. Details of torsion bar support system for supporting road-wheel hub and wheel.


TORSION BAR RETAINING BOLT
TORSION BAR RETAINING NUT
ROAD WHEEL ARM
OUTER BEARING
INNER BEARING
BEARING LOCK NUT
ROAD WHEEL ARM SUPPORT
INNER BEARING OIL SEAL
SET SCREW
NUT
WASHER
GASKET
OIL SEAL
BOLT
GASKET
BEARING RETAINER
BEARING SPACER
TORSION BAR ANCHOR
GASKET
ANCHOR RETAINER
SCREW
WASHER
BOLT
TORSION BAR

RA PD 183997

Figure 427. Road-wheel support arm and torsion bar assembly used in torsion bar suspension system—exploded view.


DUAL SUPPORT ROLLER
FILLER PLUG
SPRING SEAT PIN
SUSPENSION WHEEL
VOLUTE SPRING
SUSPENSION ARM PINS
ARM SUPPORT
SINGLE SUPPORT ROLLER
BRACKET
SHOCK ABSORBER
SUSPENSION ARM
SPRING SEATS

RA PD 183998

Figure 428. Horizontal suspension unit.

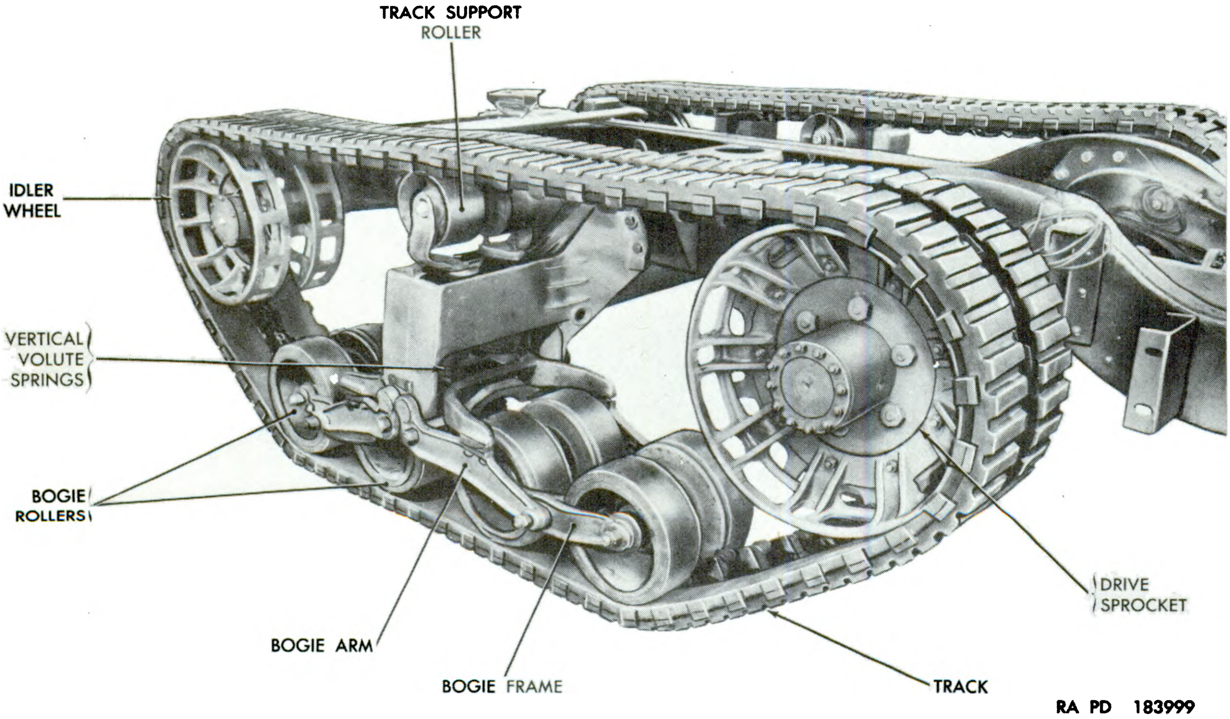

TRACK SUPPORT ROLLER
IDLER WHEEL
VERTICAL VOLUTE SPRINGS
BOGIE ROLLERS
BOGIE ARM
BOGIE FRAME
TRACK
DRIVE SPROCKET
RA PD 183999

Figure 429. Articulated suspension and track.

CHAPTER 19

WHEELS, TIRES, AND TRACKS

Section I. WHEELS

244. General

Wheels must have sufficient strength and resiliency to carry the weight of the vehicle, transfer driving and braking torque to the tires, and withstand side thrusts over a wide range of speed and road conditions. Modern speeds, which demand low centers of gravity, have resulted in the adoption of perfectly balanced wheels of small diameter. Even a slightly unbalanced condition of the wheel-and-tire assembly will cause steering troubles and rapid tire wear at high speeds; therefore, small balance weights often are attached to the wheel to remedy any unbalanced condition. Passenger car wheels are usually of the steel *disk* type. All the modern types are demountable from the brakedrum which, in addition to having a braking surface, serves as the true hub for mounting the wheel upon the axle spindles. Modern trucks use demountable disk wheels of this type, or cast or welded spoke wheels.

245. Disk Wheels

The disk (fig. 430) may be a solid plate or a slotted steel disk. In both cases, the disk is welded or riveted to the rim, and the wheels are demountable at the brakedrum. The disk is dished to bring the point of ground contact under the large wheel bearing and to permit the mounting of dual wheels.

246. Pressed and Cast Spoke Wheels

On light vehicles, the wheel hub and rim are connected by spokes, and the wheels are demountable at the brakedrums. For heavier trucks, the spokes are formed integral (cast) with the hub, and a demountable rim is used.

247. Wire Wheels

Wire wheels (fig. 430) are light, resilient, and easy on tires. However, they are hard to clean, permit the use of full-circle antiskid chains only, and are not adapted for use with dual wheels. The modern type consists of a pressed-steel hub and rim connected by welded, rather than adjustable (bicycle-type), spokes.

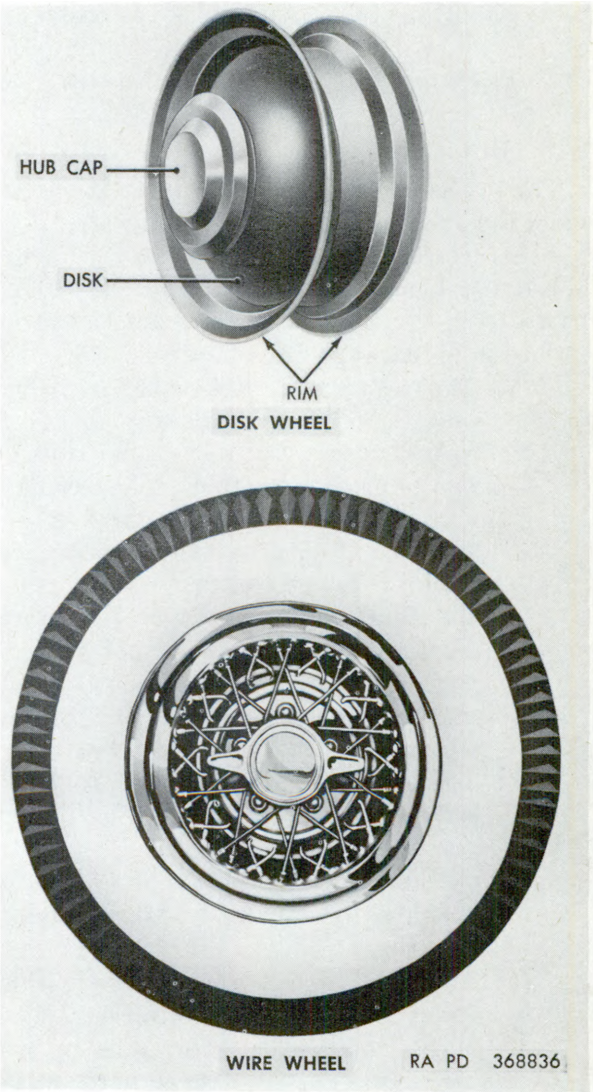


Figure 430. Disk wheel and wire wheel.

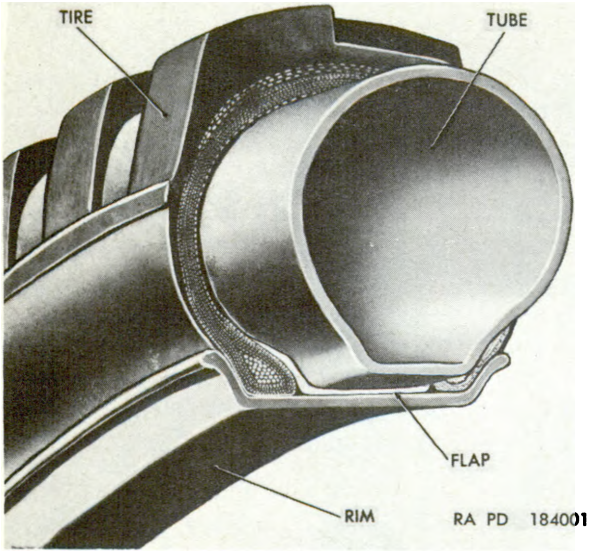


Figure 431. Tire assembly on flat base rim.

248. Tire Assembly

The tire assembly generally consists of the tire, inner tube, and flap, as shown in figure 431.

a. Structural parts of a tire are the tread, breaker, cushion, plies, and bead (fig. 432). Each part of the tire serves a definite purpose as described in (1) through (5) below.

(1) The tread is a layer of rubber on the outside circumference of the tire, and is the wearing surface. It has a nonskid design to provide traction. The tread also protects cords from cuts, bruises, and moisture. Rubber extends down over the sidewalls for protection.

(2) Breakers are layers of rubber-covered cords, similar to plies, except that the cords are spaced farther apart. Breakers distribute road shocks and prevent separation of the tread from the tire.

(3) The cushion is soft, heat-resisting rubber. It absorbs road shocks and bonds plies and breakers together.

(4) Cord plies give strength to resist internal pressure, to support loads, and absorb road shocks.

(5) The bead is that portion of the tire which serves to anchor the tire to the rim. It consists of two or more cables of steel wire impregnated with a hard rubber compound, around which the plies are wrapped, to tie the bead to the carcass proper.

b. The inner tube contains the air. The flap protects the tube in the rim and bead area.

249. Types of Tires

Standard tires are used in normal commercial and military service. Combat tires, although having the same basic construction as standard tires, are designed to operate without air pressure for a limited distance only in an emergency; they should be operated without air pressure only in combat where tactical situation requires it. A combat tire is of much heavier construction than a standard tire, has more rigid sidewalls, and its heavily cushioned plies are spaced wider apart. On the inside is a heavy section of rubber. A beadlock (fig. 433) fits between the beads to prevent the tire from slipping on the rim and to hold it in position if deflated while supporting the load.

250. Types of Treads

Nondirectional treads (fig. 434), give good traction in either direction in mud and snow, on dirt or temporary roads, and cross-country. They are also practical for hard-surfaced roads. Regular

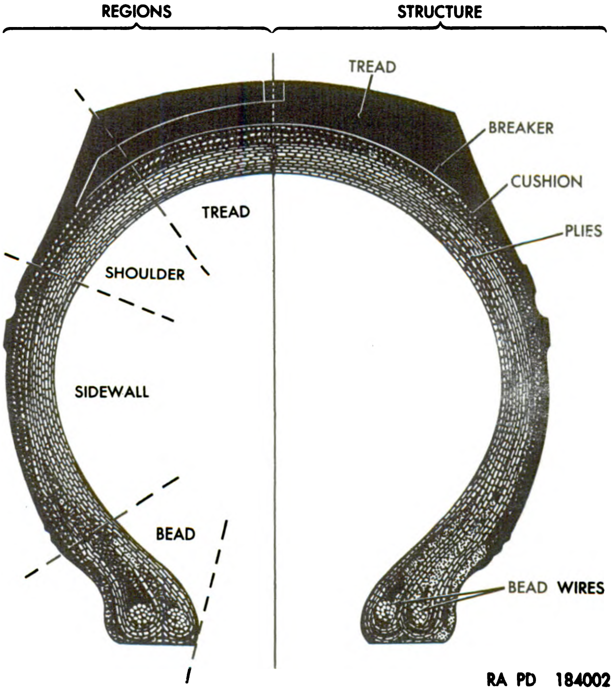


Figure 432. Tire—cross sectional view.

treads give satisfactory traction on highways and deliver long mileage.

251. Markings on Tires

a. Manufacturers' Names and Type Markings. These are imprinted on sidewalls of tires.

b. Size and Ply Marking. The size is marked on the side of each tire, for example, 7.50–20 8 ply or 8 PR (fig. 435). The first figure, 7.50, is the approximate width in inches when the tire is properly mounted on the rim and inflated but not carrying a load. The second figure, 20, is the inside diameter of the bead in inches. The third figure, if shown 8 ply, is the number of plies of cord fabric. If shown as 8 PR (ply rating), it designates that the tire is equivalent in carcass strength to an 8 ply tire, even though the tire may contain a lesser number of plies.

c. Balance Mark on Smaller Tires. On some tires a small red mark approximately one-quarter inch in diameter, on the sidewall near the bead, indicates where the valve of the tube should be placed in order to effect best balance of tire and tube. A balance mark on a tire is indicated by an arrow (fig. 436).

d. Identification of Synthetic Tires. Synthetic tires (fig. 437) usually can be identified by a red mark, approximately three-quarters inch in diameter, or by the letter "S," "S1," "S2," etc., on the sidewalls. The letter "R" identifies tires constructed of rayon fabric.

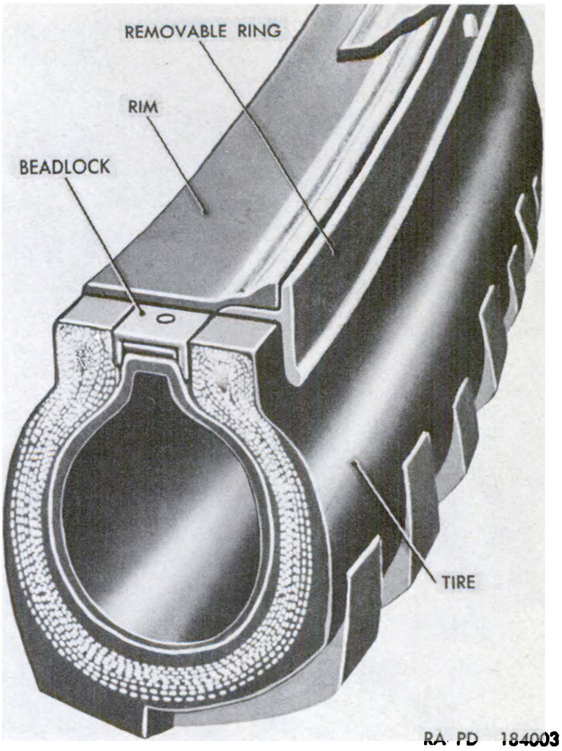

REMOVABLE RING
RIM
BEADLOCK
TIRE
RA PD 184003

Figure 433. Combat tire.

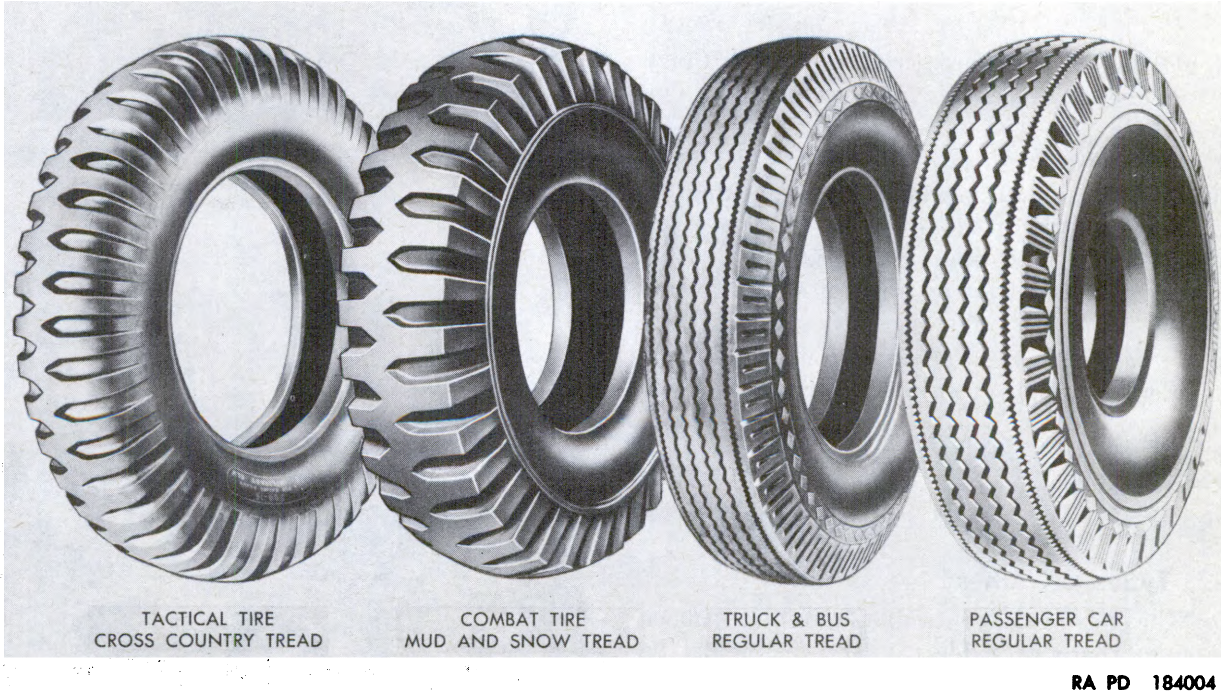

TACTICAL TIRE
CROSS COUNTRY TREAD
COMBAT TIRE
MUD AND SNOW TREAD
TRUCK & BUS
REGULAR TREAD
PASSENGER CAR
REGULAR TREAD
RA PD 184004

Figure 434. Tire treads.

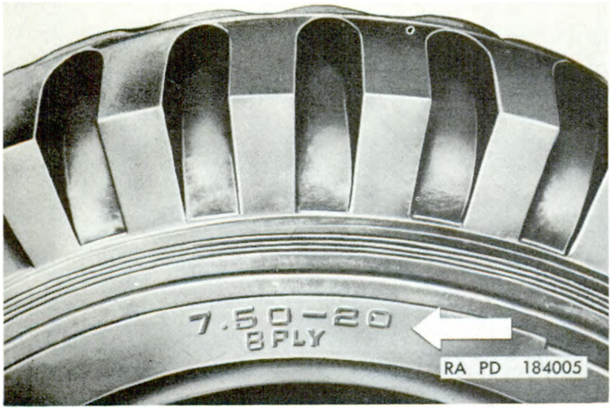


Figure 435. Size and ply markings on tires.

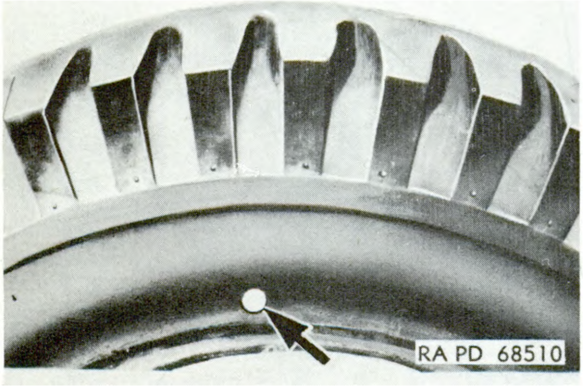


Figure 436. Balance mark on smaller tires.

e. Combat Tires. These tires are marked "Combat" on the serial number side, as shown in figure 438.

f. 6.00–16 for Beadlocks. The letters "BL" are imprinted on sidewalls near the size marking on the serial number of 6.00–16 tires which are designed for use with beadlocks (par. 254). The location of these letters on a tire is shown in figure 439.

g. Serial Number. The serial number is shown by indented numbers in the sidewall. Raised numbers in bead area indicate the number of the mold in which the tire was cured. The location of the serial number on a tire is shown in figure 440.

252. Types of Tubes

a. The tube is a continuous, circular rubber container that fits inside the tire and holds the air which supports the vehicle. Strong enough to stand only a few pounds of air pressure when not confined, the tube bears extremely high pressures when enclosed in the tire. Because the tube is made of comparatively soft rubber to fulfill its function, it is easily chafed, pinched, punctured, or otherwise damaged. Most tubes are made of butyl type of synthetic rubber (GR 1) which have air retention properties superior to natural rubber. The three types of tubes are described in *b*, *c*, and *d* below.

b. Standard tubes (fig. 441) are made of one layer of rubber molded in the shape of a doughnut. They are regularly used for standard type tires.

c. Tubes for combat tires are constructed the same as standard tubes except that they are smaller than standard tubes with the same size markings, since the inside air space of combat tires is smaller. Combat tubes are stamped "Combat" as shown in figure 442, and should always be used exclusively with combat tires.

d. Bullet-resisting tubes are of heavy, thick construction which automatically seals bullet punc-

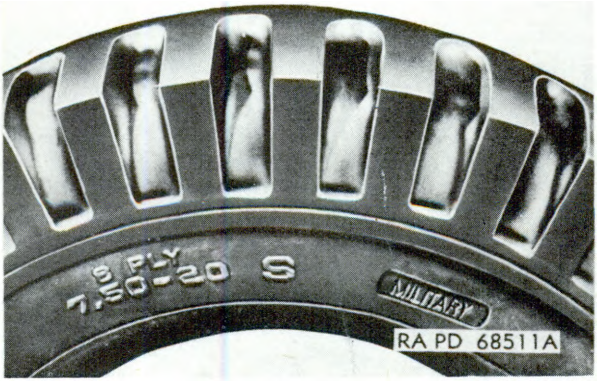


Figure 437. Identification of synthetic tires.

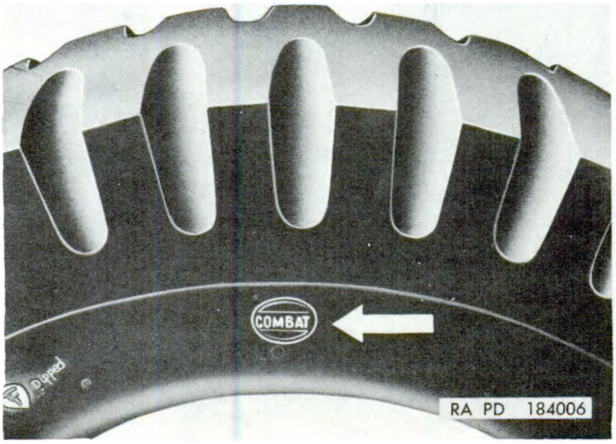


Figure 438. Combat tire markings.

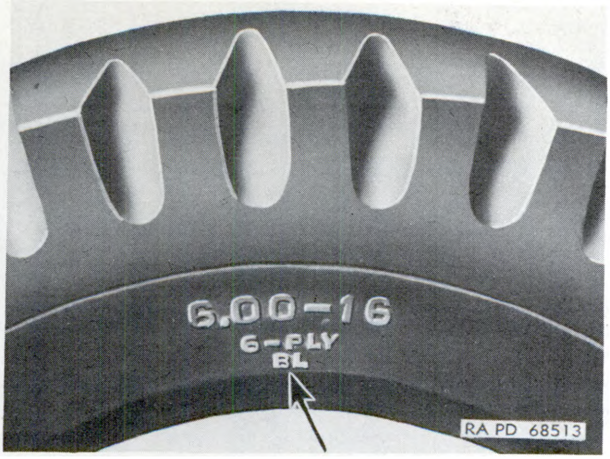


Figure 439. 6.00–16 size tire for beadlocks.

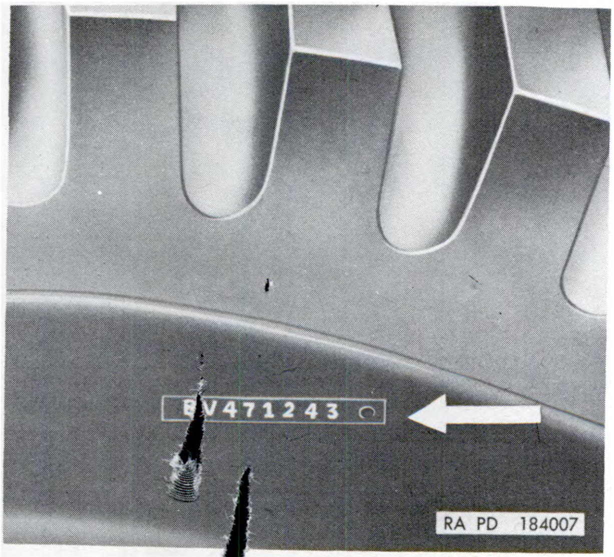


Figure [illegible]. Tire serial number.

tures. Bullet-resisting tubes are identified by their extra weight and thickness and generally have green-painted valve stems. A cross sectional view of a bullet-resisting tube is shown in figure 443.

253. Types of Rims

a. The rim completes the inclosure for the tube, holds the tire beads rigidly in place, and connects the tire to the wheel. Usually, rim and wheel are permanently fastened together as one unit and bolted to hub. On spoke-type wheels, the rim is attached with lugs. For correct mounting, demounting, and tire fit it is necessary to recognize the differences in rim types.

b. The drop-center rim (fig. 444) is made in one piece and is permanently fastened to the wheel. Its important feature is a well which permits mounting and demounting of tire. Bead seats are tapered to match a corresponding taper on the beads of the tire. Drop-center rims are generally used on smaller vehicles, such as passenger sedans and ¼-ton 4 x 4 trucks. Some passenger cars and light trucks are equipped with safety-type drop-center rims. Safety rims (fig. 444) have a slight hump at the edge of the bead ledges, which hold the beads in place when the tires go flat.

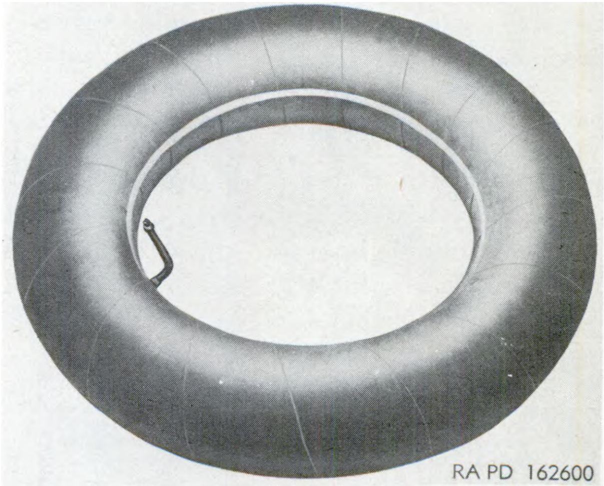


Figure 441. Standard tube—inflated.

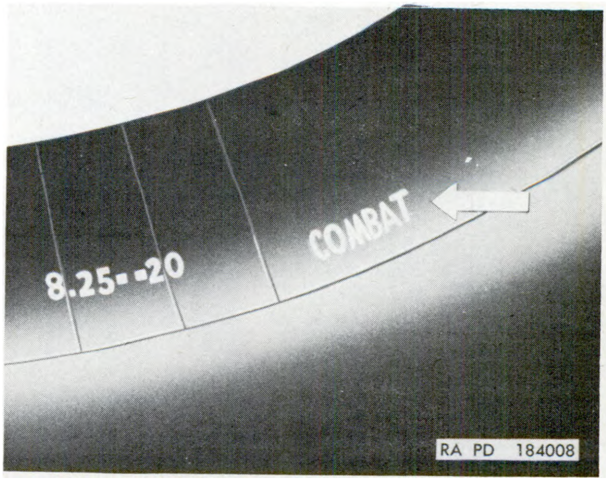


Figure 442. Standard tube for combat tires.

c. The semidrop-center rim (fig. 444) is also permanently fastened to the wheel. It has a shallow well, tapered-head seats to fit the taper of the beads of the tire, and a demountable flange. The demountable flange or side ring, which fits into a gutter on the outside edge of the rim, holds the tire in place. This type rim is standard equipment on ¾-ton 4 x 4 trucks.

d. The flat-base rim (fig. 444) is generally fastened permanently to wheels used on military vehicles. It has a flat seat for the bead, and the tires must have correspondingly flat beads. As the name indicates, the rim has no well. This type rim has a demountable side flange to permit mounting and demounting the tire. Flaps are required on the flat-base rim to protect that part of the tube not covered by the tire.

Note. Flat base rims are no longer manufactured, but are still in use in large numbers on World War II vehicles.

e. The type of divided rim shown in figure 445 is used only with small-size tires, such as those on the ¼-ton 4 x 4 truck. Note that the sections, fastened together by studs, are of equal width. The rim is built to accommodate continuous channel-type beadlocks. The rim must be divided to mount or remove the tire. Al-

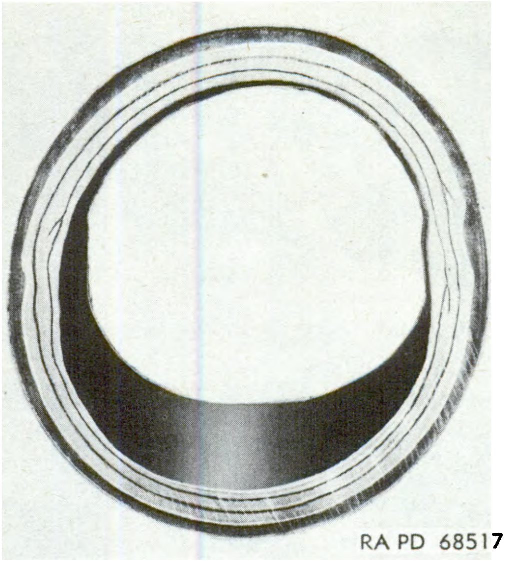


Figure 443. Bullet-resisting tube—cross sectional view.

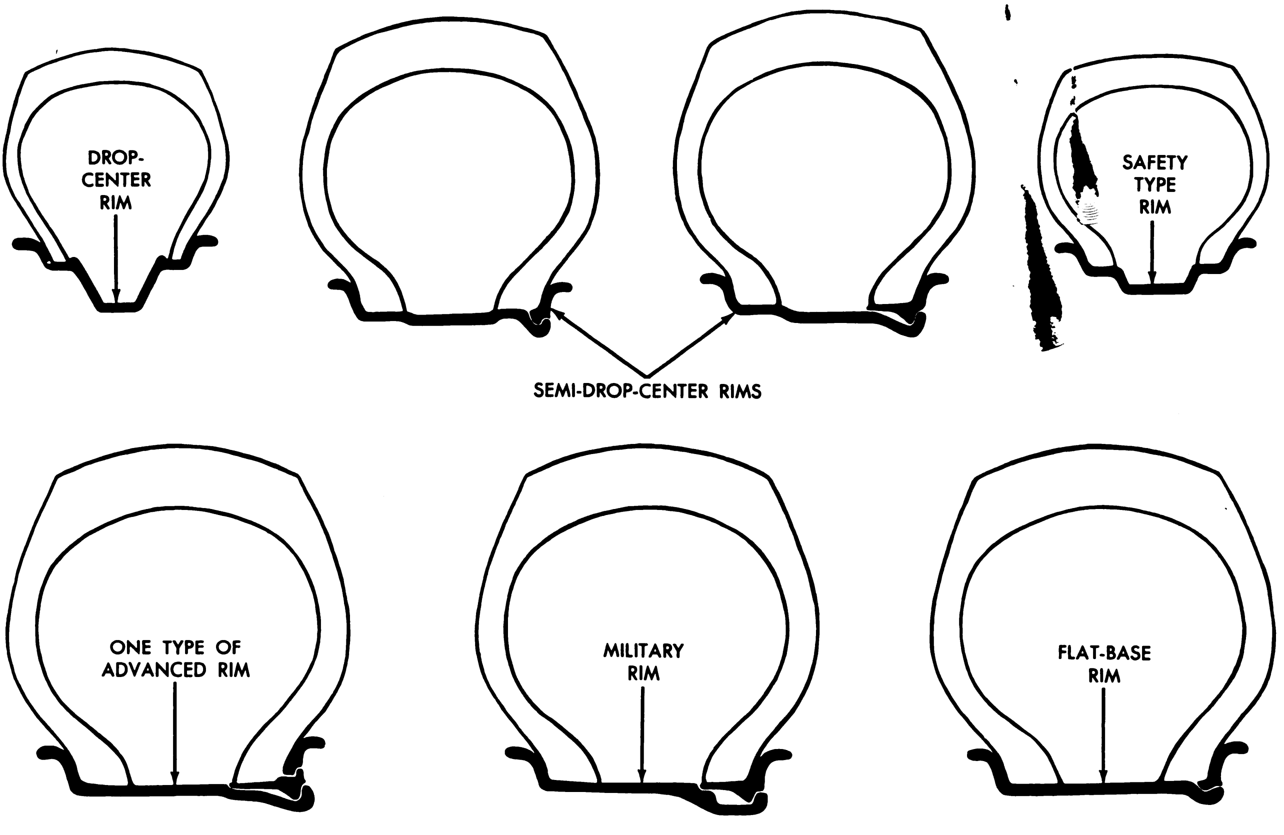
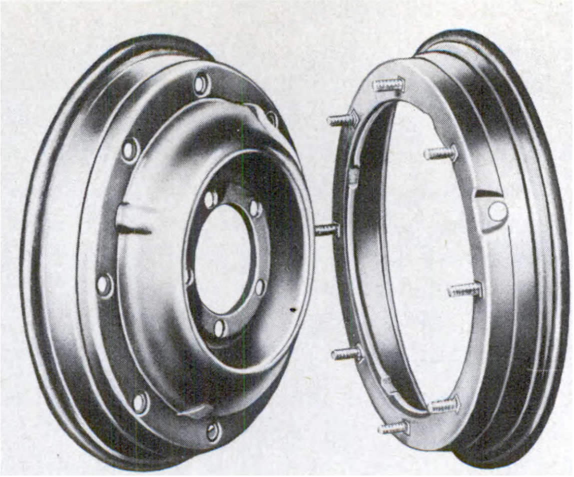


Figure 444. Types of rims.



RA PD 184010

Figure 445. Divided rims for small vehicles.

though this type of rim is designed for use with combat tires, conventional tires can be used when they have "BL" molded on the sidewalls.

f. Divided rims (fig. 446) are standard equipment on ¾-ton 4 x 4 trucks, scout cars, half-tracks, etc. The two sections of this type rim are not of equal width. They are fastened together with studs or bolts, and nuts. With this type rim, the tire is held in position by a hinged or a segmental beadlock. Divided rims are designed for use with combat tires, but standard tires can also be used. Tires are installed or removed by removing the nuts and separating the two rim sections.

g. The "advanced" rim is similar to the flat base rim, except that it has a 5° taper on each beadseat to provide a squeeze fit of the tire beads to prevent slippage. Different manufacturers have different designs of the rim base gutter area and the side ring, which prevents interchangeability.

Note. The "Military Standard" rim is an "advanced" rim with a standard rim base and side ring design which permits complete interchangeability.

254. Types of Beadlocks and Bead Clips

a. A metal device called a *beadlock* fits between the beads of the tire so that pressure can be applied by tightening the rim flanges against the outside of the bead. The beadlock is slightly wider than the space between the tire beads when mounted on the rim. Thus, a compression fit is obtained that locks the beads into place so they will not slip on the rim and will hold the tire in position. In combat this is necessary in order to support the load when operating tires without air pressure.

b. The continuous, or channel-type, beadlock (fig. 447) is a solid band of steel which can be readily inserted in its position in the tire. Flaps are not required with this type beadlock.

c. The hinged beadlock (fig. 447), through the use of a hinge, will collapse so that the diameter is smaller, permitting insertion in the tire. After insertion, it can be snapped into place between the beads. Flaps are not necessary with this beadlock.

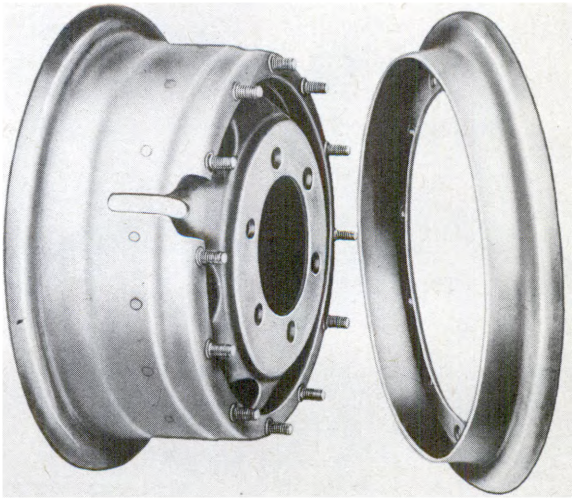
d. The segmental, or spacer-block, beadlock (fig. 447) has blocks of hard metal which are fastened together with a flexible steel band. This type can be collapsed for removal from, and insertion in, the tire. The segmental beadlock requires the use of a correct size and type rubber flap.

e. Beadlocks are identified as described in (1) and (2) below.

(1) Channel and hinged types—size and code number which give date of manufacture are stamped near valve hole.

(2) Segmental type—size and code number are stamped on rim side of each segment.

f. Bead clips (figs. 448 and 449) are used in lieu

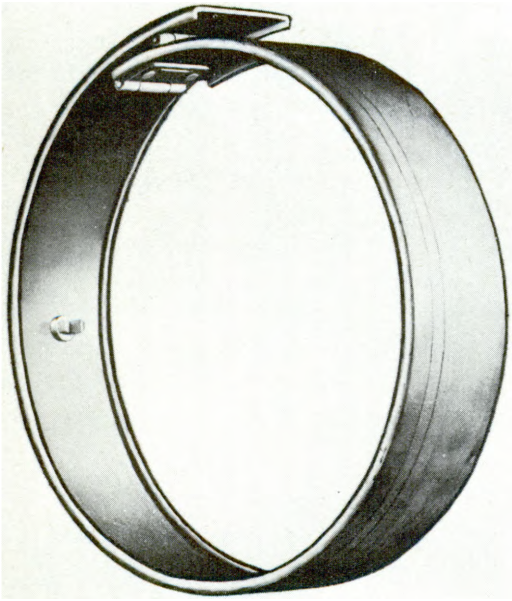


RA PD 184011

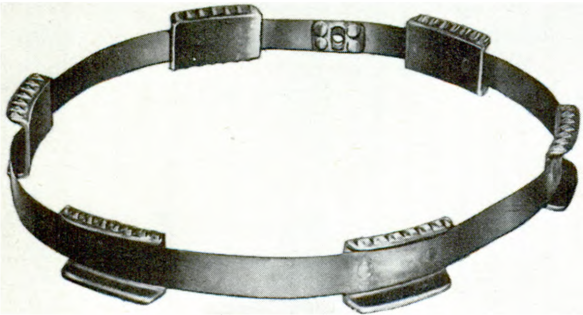
Figure 446. Divided rims for large vehicles.

of beadlocks on certain sizes of tires. Bead clips are used in multiples (5 to 6 clips are equally spaced on each bead of the tire). Figure 449 shows how the bead clip holds the tire in place.

CHANNEL



HINGED



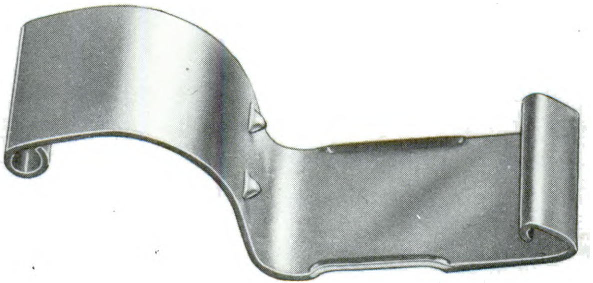
SEGMENTAL RA PD 184012

Figure 447. Channel-, hinged-, and segmental-type beadlocks.

255. Types of Valves

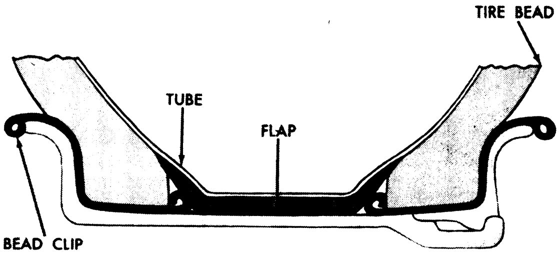
a. Tubes are inflated by air under pressure being forced into the tube through the valve, which automatically prevents air from escaping. The valve stem is threaded inside and out at the end to accommodate the valve core and cap. Stems on truck tubes are bent to make them more accessible for inflation. Valves are classified according to the method of mounting on tube.

b. The cured-in rubber-covered valve (fig. 450) is vulcanized directly into the tube and cannot be removed unless cut off for replacement. It is used on passenger cars and some light trucks. It is made in two types: nonbendable, such as used on cars; and hand-bendable, such as used on ¼-ton 4 x 4 trucks.

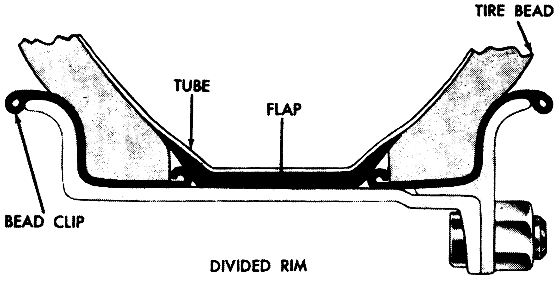


RA PD 162646

Figure 448. Bead clip.



MILITARY RIM



DIVIDED RIM

RA PD 184013

Figure 449. Bead clips installed.

c. The all-metal, cured-in valve (fig. 451) is vulcanized to the tube and cannot be removed. This type of valve is now used in practically all tubes for vehicles equipped with advanced rims.

d. The spud-mounted valve (fig. 452) has two parts for attaching to the tube. The spud is inserted in the tube and the stem is screwed down on the spud, making an airtight seal.

e. The clamp-in valve (fig. 453) is inserted into the tube and is held in place by a bridge washer and valve nut. The bridge washer is positioned so that the ends point lengthwise with the tube.

256. Valve Accessories

a. The valve core is screwed into the stem and permits air under pressure to enter, but prevents it from escaping.

(1) The shell of the visible-spring valve core (fig. 454) has a rubber washer which fits airtight against the tapered seat inside the stem. In closed position, a spring holds a rubber-seated cup firmly against the shell. In open position, the pin forces spring and cup away from shell.

(2) In the concealed-spring valve core (fig. 455) the spring is enclosed within the shell, but it operates the same way and is interchangeable with the visible spring core.

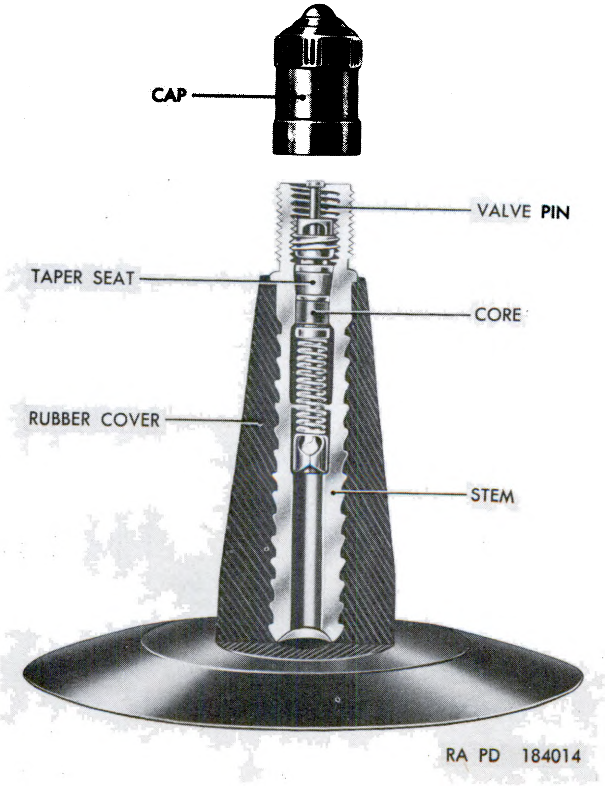

CAP
VALVE PIN
TAPER SEAT
CORE
RUBBER COVER
STEM
RA PD 184014

Figure 450. Rubber-covered valve.

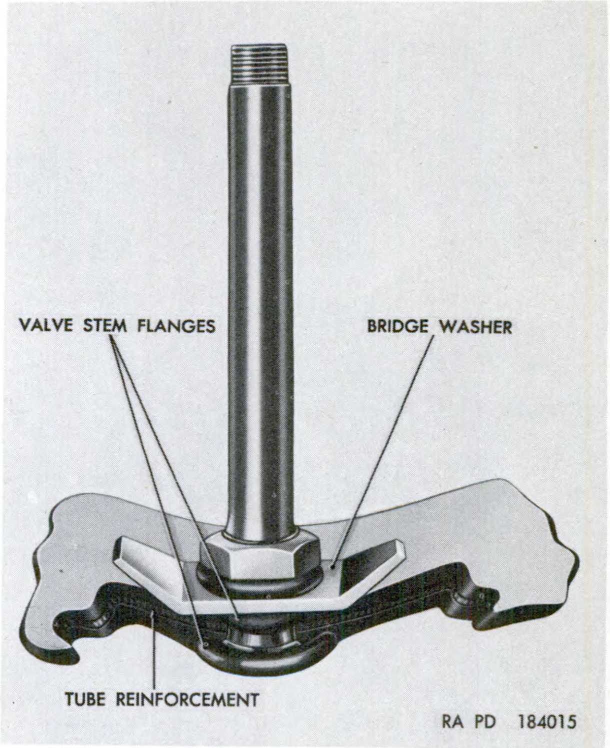

VALVE STEM FLANGES
BRIDGE WASHER
TUBE REINFORCEMENT
RA PD 184015

Figure 451. All-metal cured-in valve.

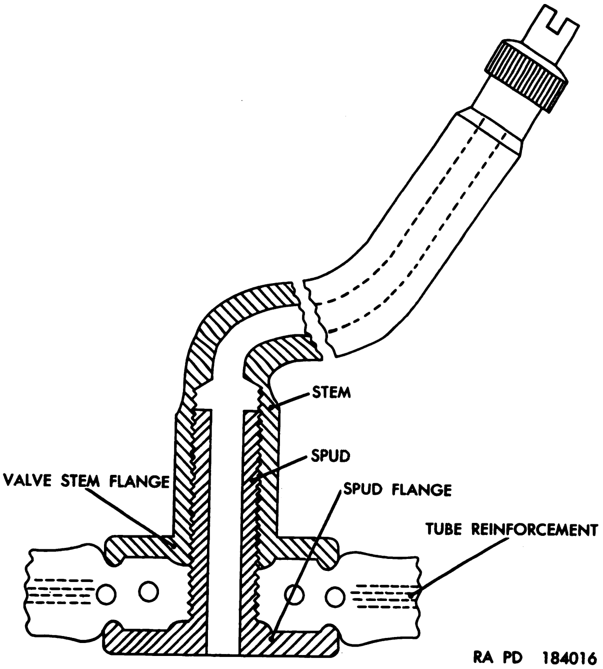

STEM
SPUD
VALVE STEM FLANGE
SPUD FLANGE
TUBE REINFORCEMENT
RA PD 184016

Figure 452. Spud-mounted valve.

b. The valve cap (fig. 456) keeps the core clean and serves as the final seal. The screwdriver type has a forked tip which can be used to remove and replace valve cores.

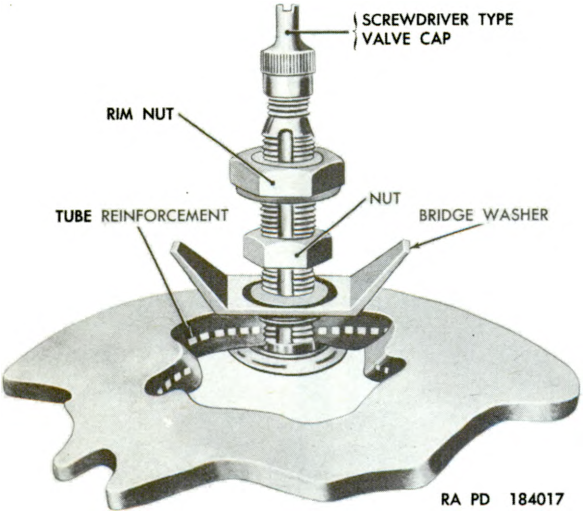

SCREWDRIVER TYPE VALVE CAP
RIM NUT
NUT
TUBE REINFORCEMENT
BRIDGE WASHER
RA PD 184017

Figure 453. Clamp-in valve.

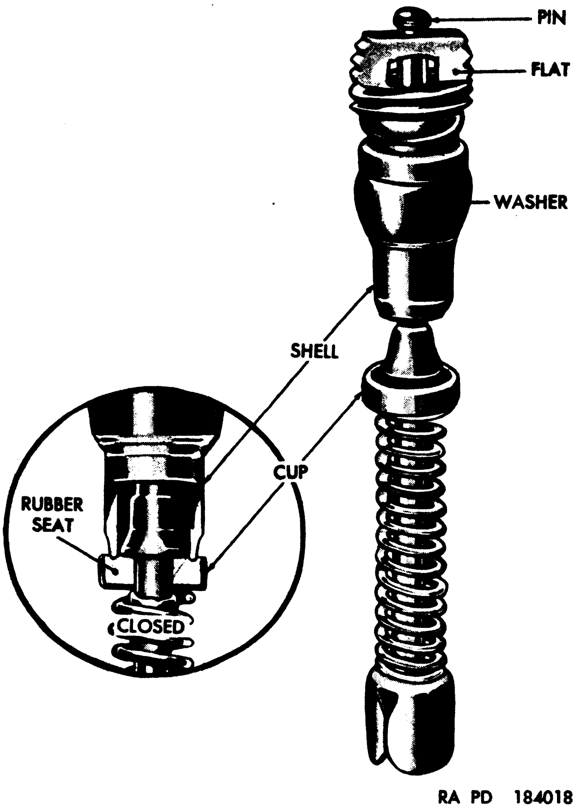

PIN
FLAT
WASHER
SHELL
CUP
RUBBER SEAT
CLOSED
RA PD 184018

Figure 454. Visible-spring valve core.

c. The valve stem repair tool (fig. 457) has four uses. The forked end removes and replaces cores, the tap cleans the inside threads, the die cleans the outside thread, and the cutter smooths burred valves.

d. A gage is necessary to determine correct air pressure. The dual foot-chuck hand gage (fig. 458) simplifies checking of dual tires since the dual foot chuck is so arranged that it can easily reach the inner valve stem of the tire.

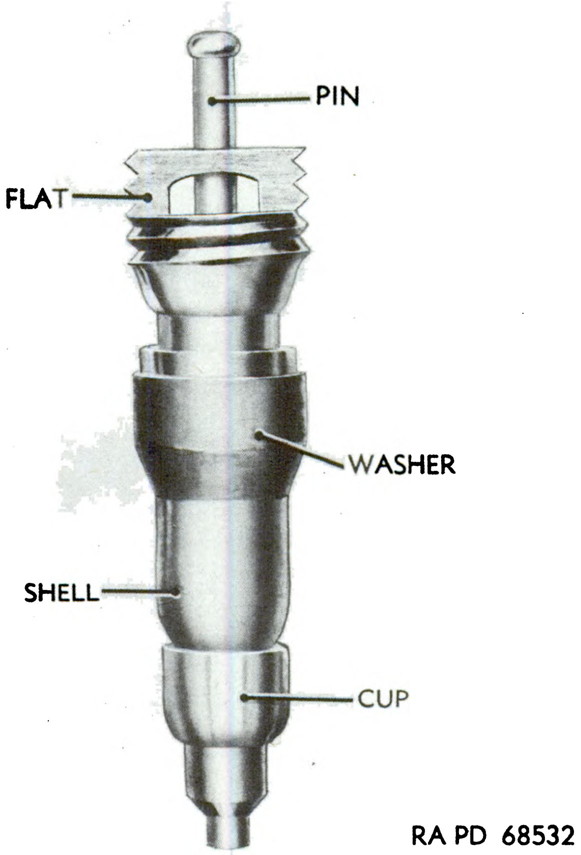

PIN
FLAT
WASHER
SHELL
CUP
RA PD 68532

Figure 455. Concealed-spring valve core.

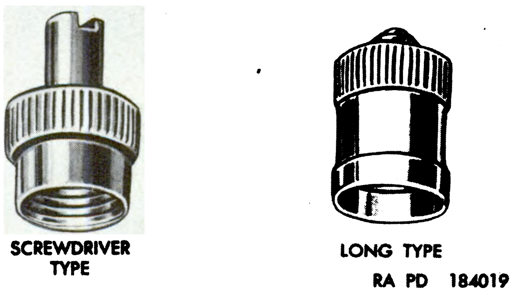

SCREWDRIVER TYPE
LONG TYPE
RA PD 184019

Figure 456. Valve caps.

e. Another type gage (fig. 459), is a combination device which can be used to check air pressure as well as to inflate the tube from a compressed air source.

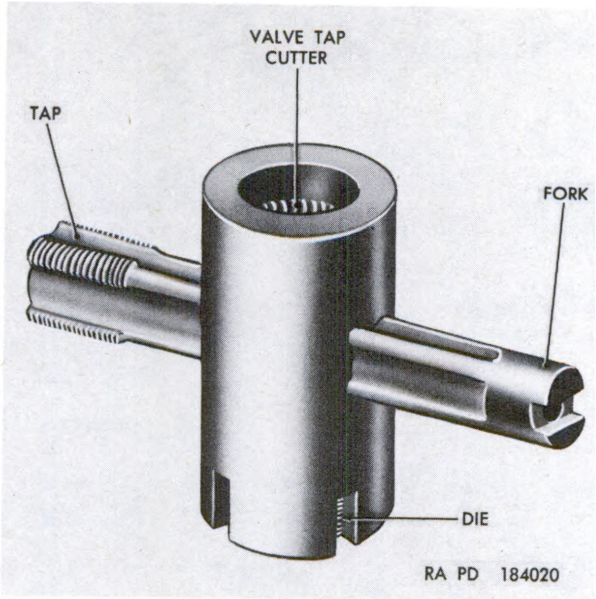

VALVE TAP CUTTER
TAP
FORK
DIE
RA PD 184020

Figure 457. Valve tool.

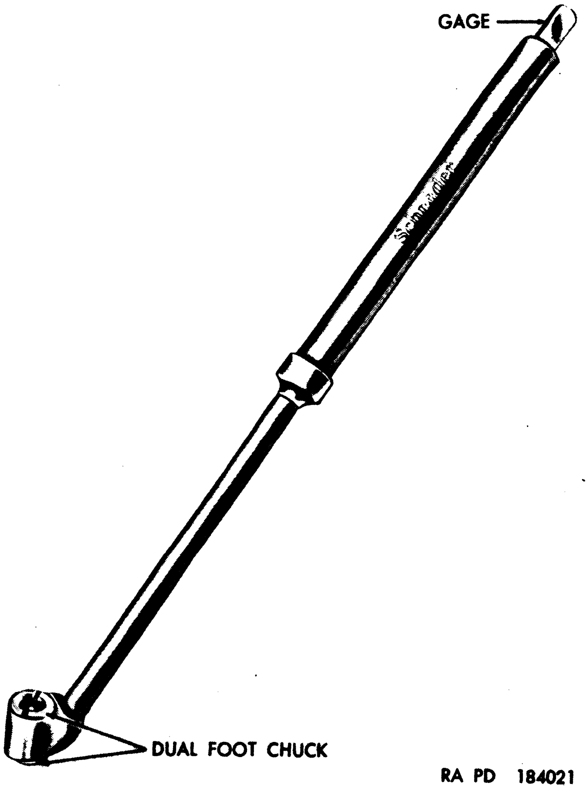

GAGE
DUAL FOOT CHUCK
RA PD 184021

Figure 458. Dual foot chuck hand gage.

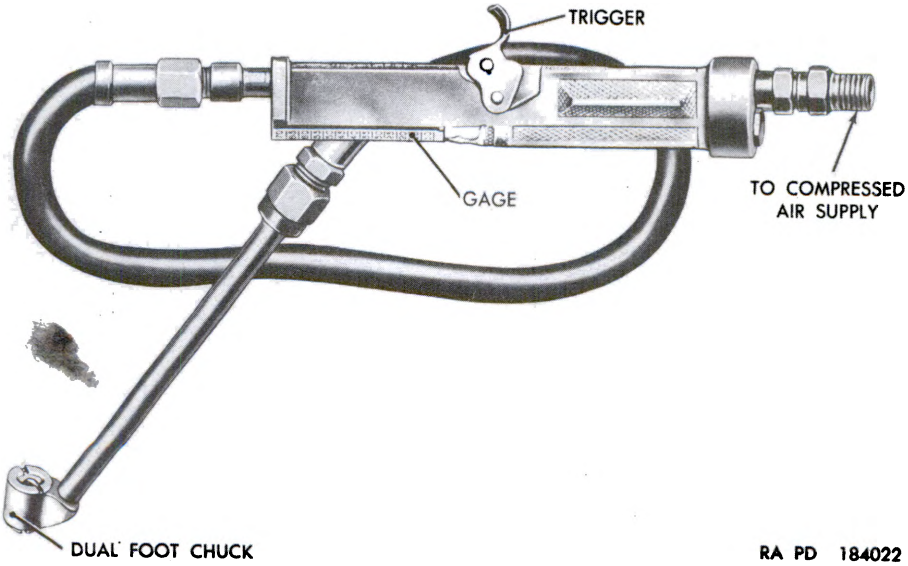

TRIGGER
GAGE
TO COMPRESSED AIR SUPPLY
DUAL FOOT CHUCK
RA PD 184022

Figure 459. Dual foot chuck and gage.

Section III. TRACKS

257. Tracklaying Vehicles

Two individually driven tracks provide the traction necessary to propel a tracklaying vehicle. Each track consists of individual track blocks, held together by steel connectors between track block pins to form a continuous track. Each

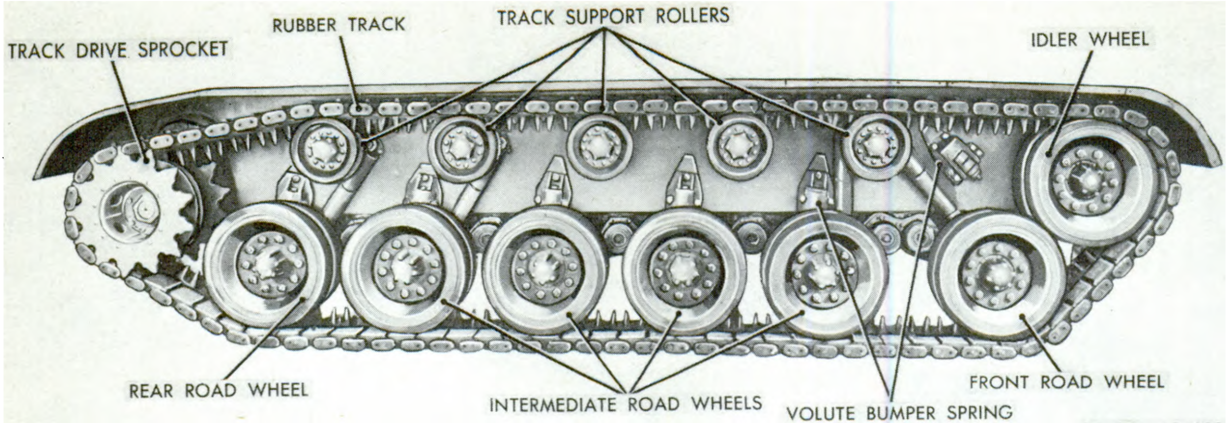

TRACK DRIVE SPROCKET
RUBBER TRACK
TRACK SUPPORT ROLLERS
IDLER WHEEL
REAR ROAD WHEEL
INTERMEDIATE ROAD WHEELS
VOLUTE BUMPER SPRING
FRONT ROAD WHEEL
RA PD 184023

Figure 460. Track and suspension.

rubber track block consists of a rubber block molded around two forged steel tubes, and connected at each end by end connectors or steel links. See figures 460 and 461 for details of construction. Steel tracks are made up of steel track blocks, connected in the same way as the rubber blocks. The track block pins are not an integral part of the block, but are assembled into the forged tubes. Doughnut-shaped rubber spacers are molded onto each pin and form the bond between the pin and the forged tube. So that the entire track can be electrically grounded, each pin has two bronze clips which make contact between the pin and the tube. Since rubber track blocks are entirely symmetrical, with the same amount of rubber on each side, they can be turned over to give added service after one side has become badly worn (except for rubber tracks with chevron tread). Steel tracks cannot be turned. Drive sprockets on each side of the vehicle pull the tracks forward over the supporting rollers and lay them down in the path of the advancing track wheels.

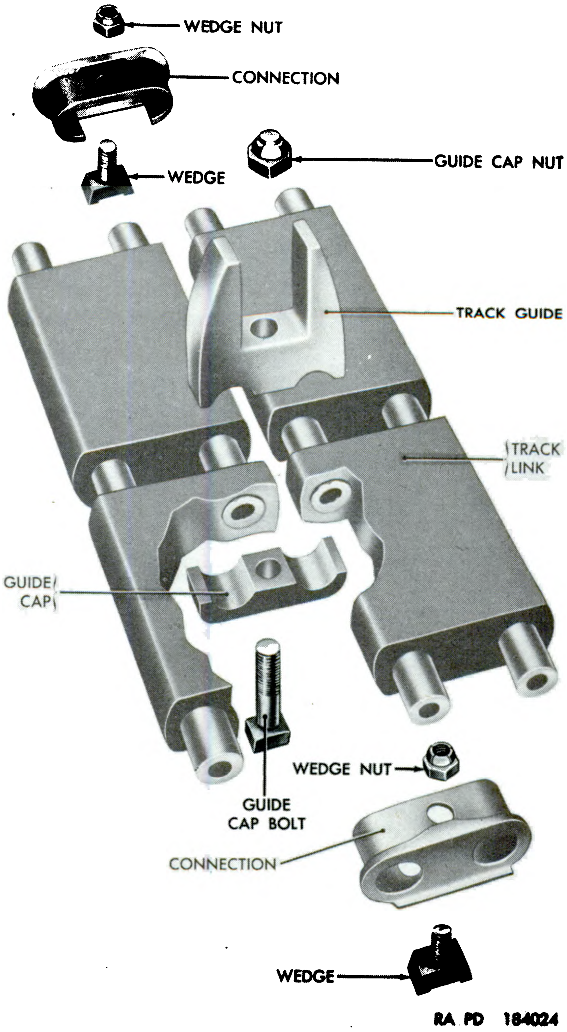
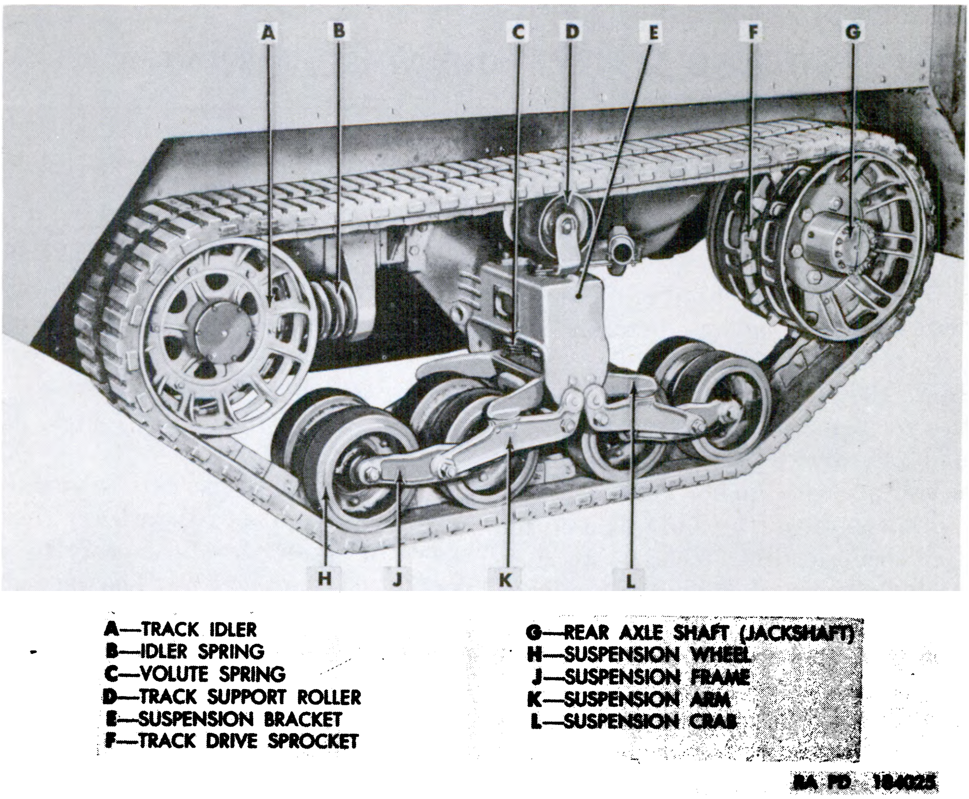

WEDGE NUT
CONNECTION
GUIDE CAP NUT
WEDGE
TRACK GUIDE
TRACK LINK
GUIDE CAP
WEDGE NUT
GUIDE CAP BOLT
CONNECTION
WEDGE
RA PD 184024

Figure 461. Center guide rubber track links.

258. Half-Tracks

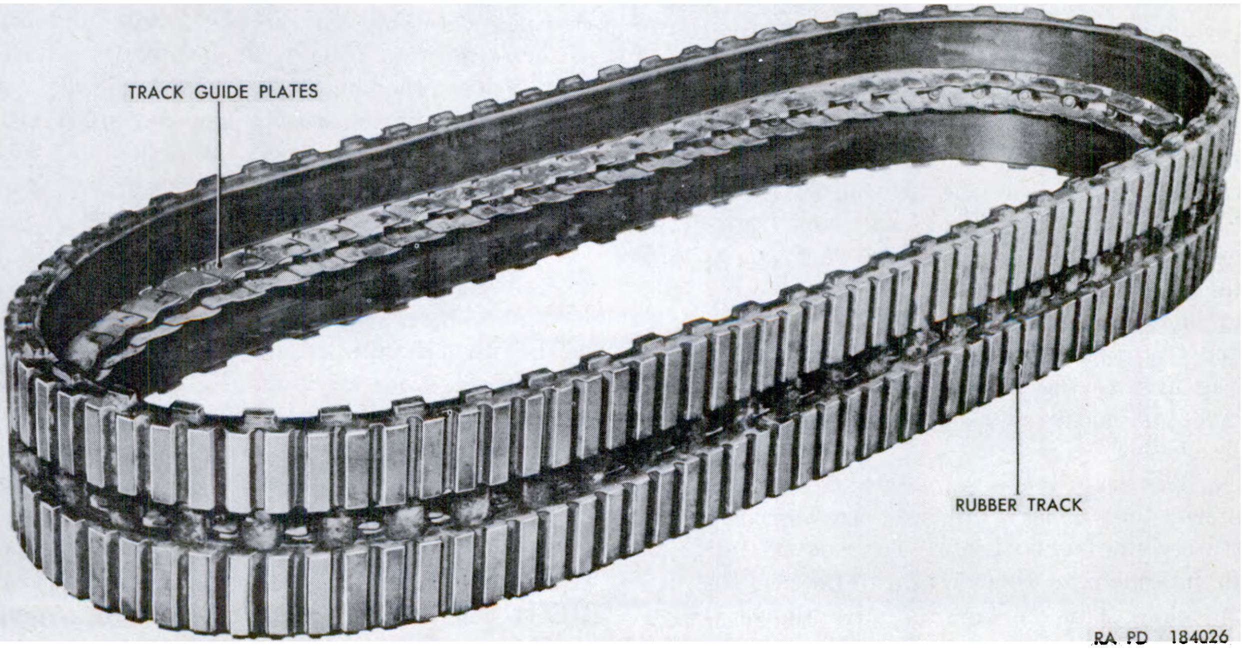
The half-track derives its name from the type of suspension supporting the rear of the vehicle. Two tracks, supported by rollers, are driven by sprockets on the rear axle and drive the vehicle. The tracks are the endless-band type, made of rubber molded to steel cables which extend throughout the track length. Metal guide plates with steel cross members are bolted to the cables along the inside center of the tracks. These serve as contacts for the jackshaft driving sprocket teeth and as guides to keep the tracks on the bogie rollers and sprockets. The edges of the track incorporate projections, or tabs, for added traction.

The tracks are provided with nondirectional-type treads which operate equally as well in one direction as the other; however, the center guides are not uniform in width, and do not operate satisfactorily with the wide part of the guide in the forward position. Figures 462 and 463 illustrate constructional details of a track and the method of supporting and driving it.


A
B
C
D
E
F
G
H
J
K
L
A—TRACK IDLER
B—IDLER SPRING
C—VOLUTE SPRING
D—TRACK SUPPORT ROLLER
E—SUSPENSION BRACKET
F—TRACK DRIVE SPROCKET
G—REAR AXLE SHAFT (JACKSHAFT)
H—SUSPENSION WHEEL
J—SUSPENSION FRAME
K—SUSPENSION ARM
L—SUSPENSION CRAB

RA PD 184025

Figure 462. Bogie and track assembly.


TRACK GUIDE PLATES
RUBBER TRACK

RA PD 184026

Figure 463. Rubber track assembly.

CHAPTER 20

STEERING SYSTEMS AND WHEEL ALINEMENT

Section I. STEERING SYSTEMS

259. Steering Methods

a. In order to steer a vehicle, the wheels must be changed from their straight-ahead position. An early method of steering was by means of a "fifth wheel," which serves as a central pivot for the entire front axle, as shown in figure 464. This method serves for vehicles that are pulled, such as trailers and horsedrawn vehicles, but it is not practical for self-propelled motor vehicles.

b. The Ackerman system (fig. 464), is used for automotive vehicles. In this method of steering, the front wheels are mounted on pivoted knuckles, and a steering linkage is used to tie the knuckles together so that the wheels rotate together about their pivots.

260. Steering Linkage

(figs. 465 and 466)

a. A steering knuckle arm is bolted and keyed to each steering knuckle. A 2-bolt fastening is sometimes used to reduce localization of stress. The knuckle arms are connected by a tie rod to tie the knuckles together. A drag link is attached to one knuckle arm for turning the steering knuckles about their pivots. This drag link is connected to the pitman arm (steering gear arm), which is operated by the steering gear.

b. One of the steering knuckles may have two separate knuckle arms, one for the tie rod and the other for the drag link. A double arm (the left steering knuckle arm in fig. 465) is frequently used to provide for these two connections. The drag link usually extends in the direction of the frame side members, though it may extend across the chassis.

c. The drag link is sometimes connected to an intermediate knuckle arm supported on the frame between the front wheels. Tie rods extend from the intermediate knuckle arm to the two steering knuckles. This linkage is advantageous with parallel arm suspension (knuckle arms parallel with each other), since each tie rod will move with its corresponding arm so that vertical movement of the wheels does not disturb the wheel alinement or otherwise affect steering. The drag link is sometimes eliminated and the tie rods connected directly to the pitman arm.

261. Tie Rod

a. The tie rod is usually located behind the axle or the centerline of the wheels, though it may be located to the front. It may be of tubular or solid rod construction. The rod is threaded at the ends and is screwed into the tie rod end (fig. 467). The length of the tie rod can be adjusted to keep the front wheels in proper alinement and can be secured by the tie rod and clamp bolts.

b. Owing to the relative motion between the tie rod and the knuckle arms, it is necessary to have a swiveling connection between them. The tie rod end is usually fastened to the knuckle arm with a stud. Some form of socket is provided within the tie rod end to hold the end of the stud, which is in the form of a ball or yoke, and to allow movement between the knuckle arm and the tie rod. A lubricating fitting is usually provided to keep the ball-and-socket joint properly lubricated. A dust seal covers the tie rod end to prevent dust from entering the joint and loss of the lubricant.

262. Drag Link

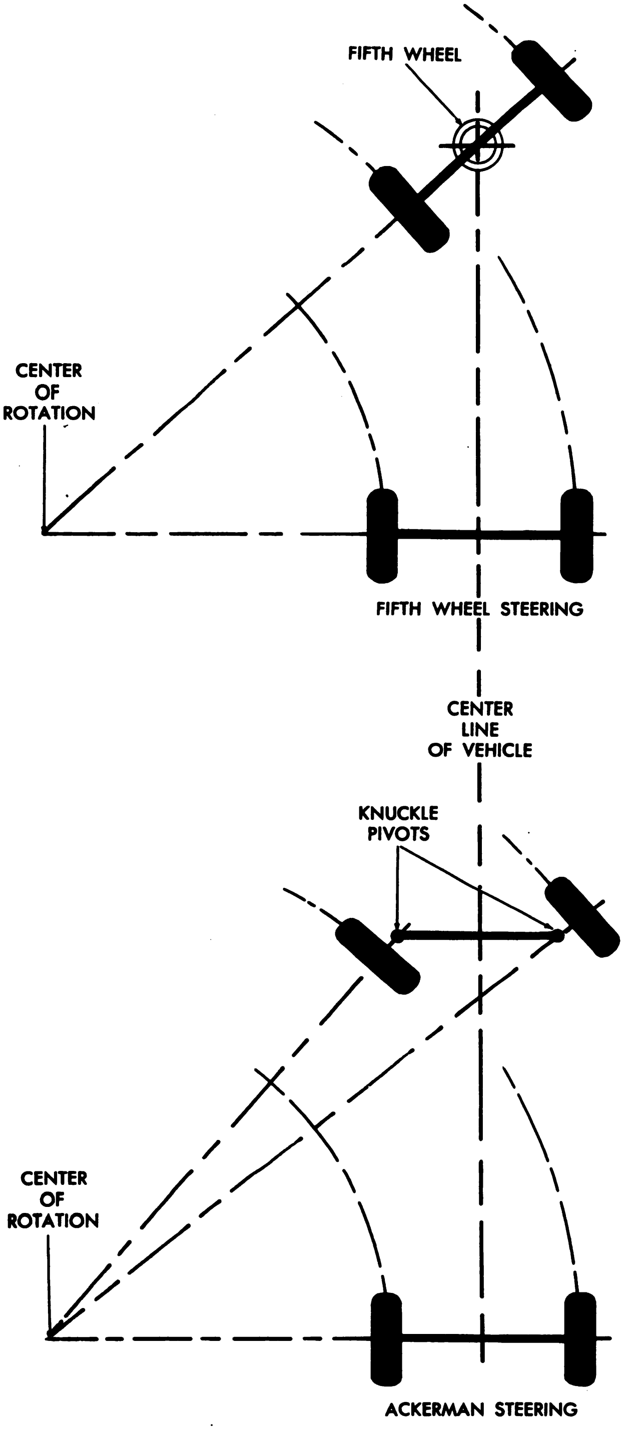
a. The length of the drag link (fig. 465) should be such that the pitman arm is vertical when the front wheels are straight ahead. Maximum leverage is then available for turning the wheels. The drag link is made in tubular or rod form, and is provided with springs to cushion shocks and prevent their transmission to the steering gear.

b. A housing is provided on one end of the drag link to receive the ball end of the pitman arm. Ball sockets, coil springs, spring seats, and a screw plug secured by a cotter pin are inserted into this housing (figs. 468 and 469), to hold the pitman arm ball. Sometimes the slot through which the pitman arm is inserted extends the entire length of the housing, in which case the end of the housing has a screw cap. The end of the drag link attached to the steering knuckle arm is usually somewhat similar, though it may be made like a tie rod end.

c. Lubricating fittings are provided for each joint. Dust shields are fitted over the ball-and-socket joints to hold in the lubricant and to prevent dust entering the joint.

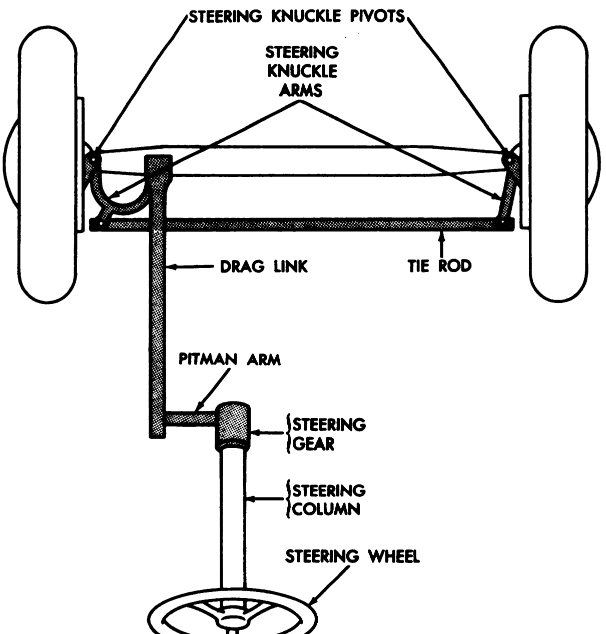
263. Steering Gears

a. A steering gear, mounted on the end of the steering column, operates the pitman arm which moves the steering linkage. A steering gear should permit easy steering without too many revolutions of the steering wheel to turn the vehicle wheels from hard over one way to hard over the other. Steering gears provide reductions of 11 or 12 : 1 for light cars, and up to 18 : 1, or more, for


FIFTH WHEEL
CENTER OF ROTATION
FIFTH WHEEL STEERING
CENTER LINE OF VEHICLE
KNUCKLE PIVOTS
CENTER OF ROTATION
ACKERMAN STEERING

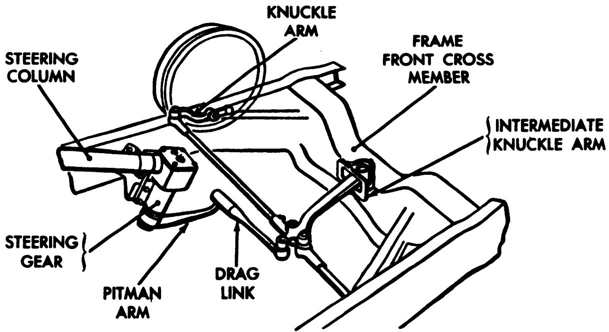
RA PD 184027

Figure 464. Methods of steering.


STEERING KNUCKLE PIVOTS
STEERING KNUCKLE ARMS
DRAG LINK
TIE ROD
PITMAN ARM
STEERING GEAR
STEERING COLUMN
STEERING WHEEL

RA PD 184028

Figure 465. Steering linkage.


KNUCKLE ARM
STEERING COLUMN
FRAME FRONT CROSS MEMBER
INTERMEDIATE KNUCKLE ARM
STEERING GEAR
PITMAN ARM
DRAG LINK

RA PD 184029

Figure 466. Steering linkage with intermediate knuckle arm.

heavy trucks. This means the steering wheel must be turned from 2½ to 3½ complete revolutions (turning the pitman arm through an arc of about 70°) to turn the wheels from hard over one way to hard over the other.

b. Steering gears are designed so that they will transmit motion very easily in one direction for steering and transmit practically no motion in the other direction so as to reduce to a minimum the transmission of shocks to the driver.

c. Some of the early steering gears were the plain pinion and bevel gear type, some were the planetary type, others were spur gears. Some form of modification of the worm-and-gear principle is now the most widely used.

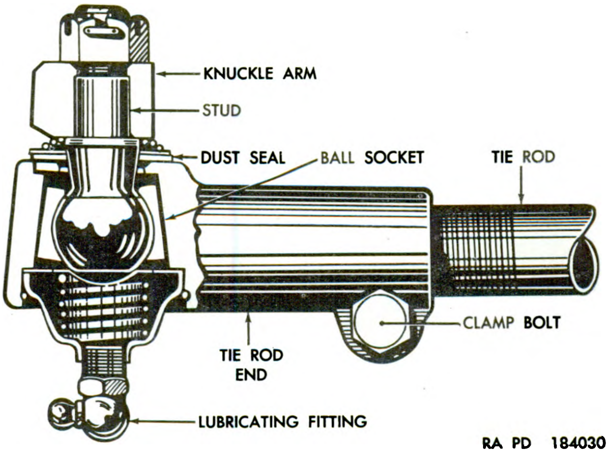

KNUCKLE ARM
STUD
DUST SEAL
BALL SOCKET
TIE ROD
CLAMP BOLT
TIE ROD END
LUBRICATING FITTING
RA PD 184030

Figure 467. Tie rod end.

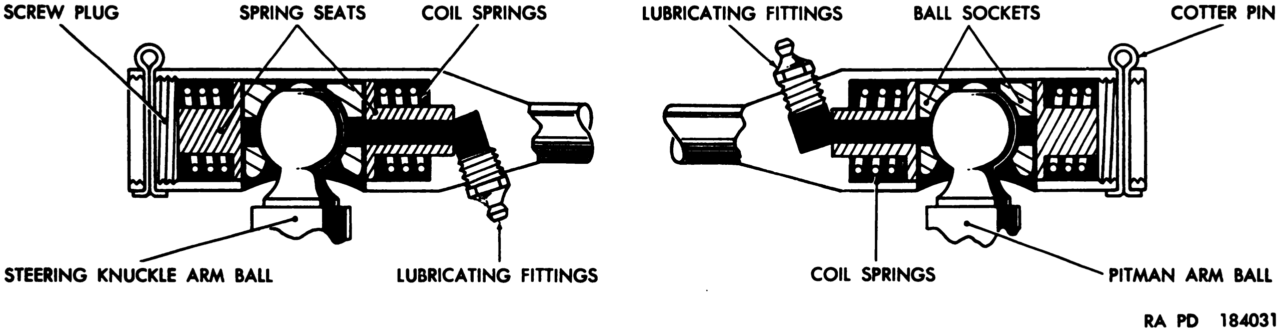

SCREW PLUG
SPRING SEATS
COIL SPRINGS
LUBRICATING FITTINGS
BALL SOCKETS
COTTER PIN
STEERING KNUCKLE ARM BALL
LUBRICATING FITTINGS
COIL SPRINGS
PITMAN ARM BALL
RA PD 184031

Figure 468. Drag link—cross sectional view.

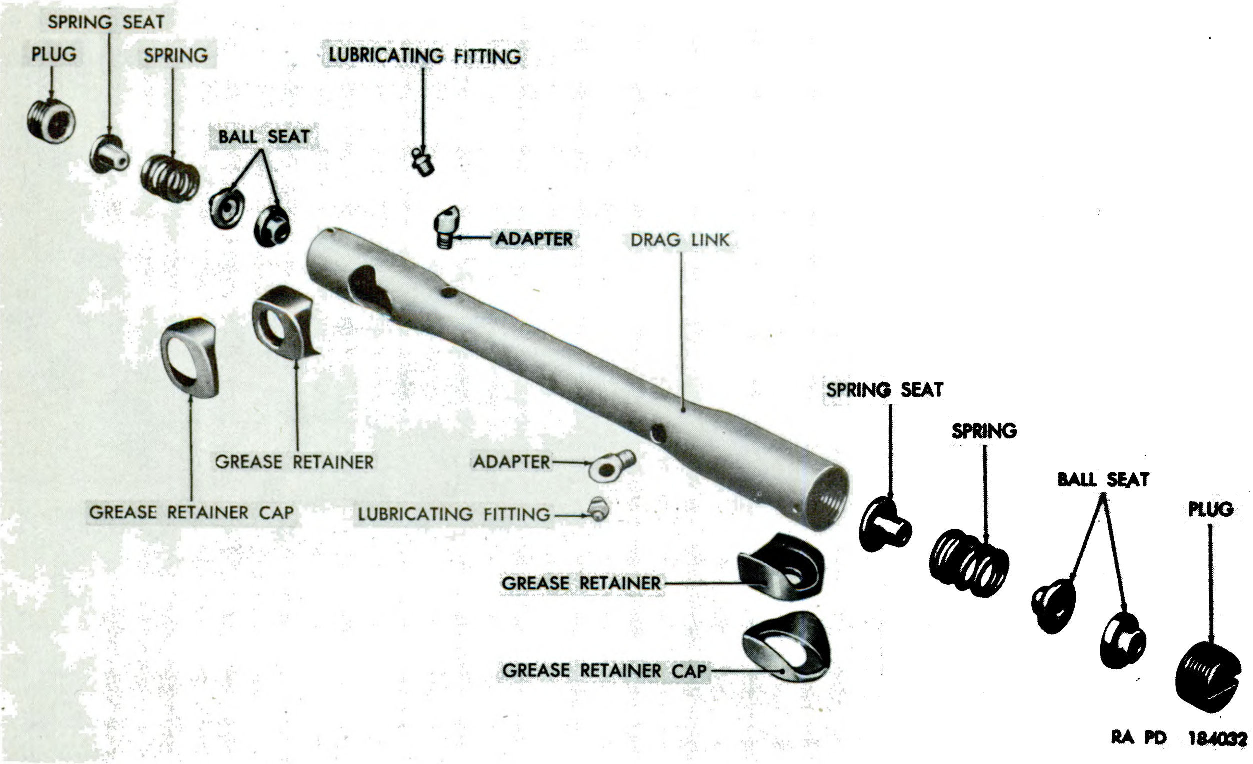

SPRING SEAT
PLUG
SPRING
LUBRICATING FITTING
BALL SEAT
ADAPTER
DRAG LINK
GREASE RETAINER
GREASE RETAINER CAP
ADAPTER
LUBRICATING FITTING
GREASE RETAINER
GREASE RETAINER CAP
SPRING SEAT
SPRING
BALL SEAT
PLUG
RA PD 184032

Figure 469. Drag link—disassembled view.

d. The steering wheel is mounted on the top of the steering column and turns a shaft within the steering column. This shaft has a worm mounted on its lower end within the steering gear housing. The worm is geared to the pitman arm shaft that contains the pitman arm. The method of gearing the steering column shaft to the pitman arm shaft varies considerably with different types of steering gears.

264. Worm-and-Sector Steering Gears

a. In this type of steering gear (figs. 470 and 471) the pitman arm shaft carries a gear that meshes with the worm on the steering gear shaft. Generally, only a sector of a gear is used since it turns through an arc of only 70°.

b. The steering wheel turns the worm on the lower end of the steering gear shaft, which rotates the sector and the pitman arm shaft carrying the pitman arm. The worm is assembled between tapered roller bearings which take both thrust and load. An adjusting nut or plug is provided for adjusting the end play of the worm. Some means of adjusting the end play of the cross shaft is also provided.

265. Worm-and-Roller Steering Gear

a. The worm-and-roller steering gear (fig. 472) is quite similar to the worm-and-sector type except that a roller is supported by ball or roller bearings within the sector mounted on the pitman arm shaft. These bearings assist in cutting down fric-

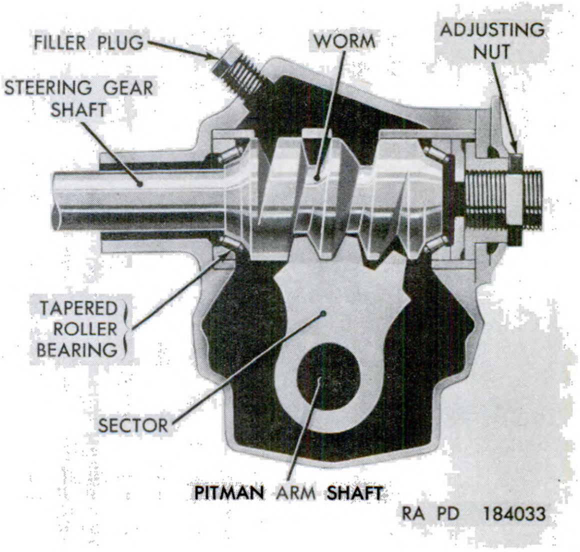

FILLER PLUG
WORM
ADJUSTING NUT
STEERING GEAR SHAFT
TAPERED ROLLER BEARING
SECTOR
PITMAN ARM SHAFT
RA PD 184033

Figure 470. Simple worm-and-sector steering gear.

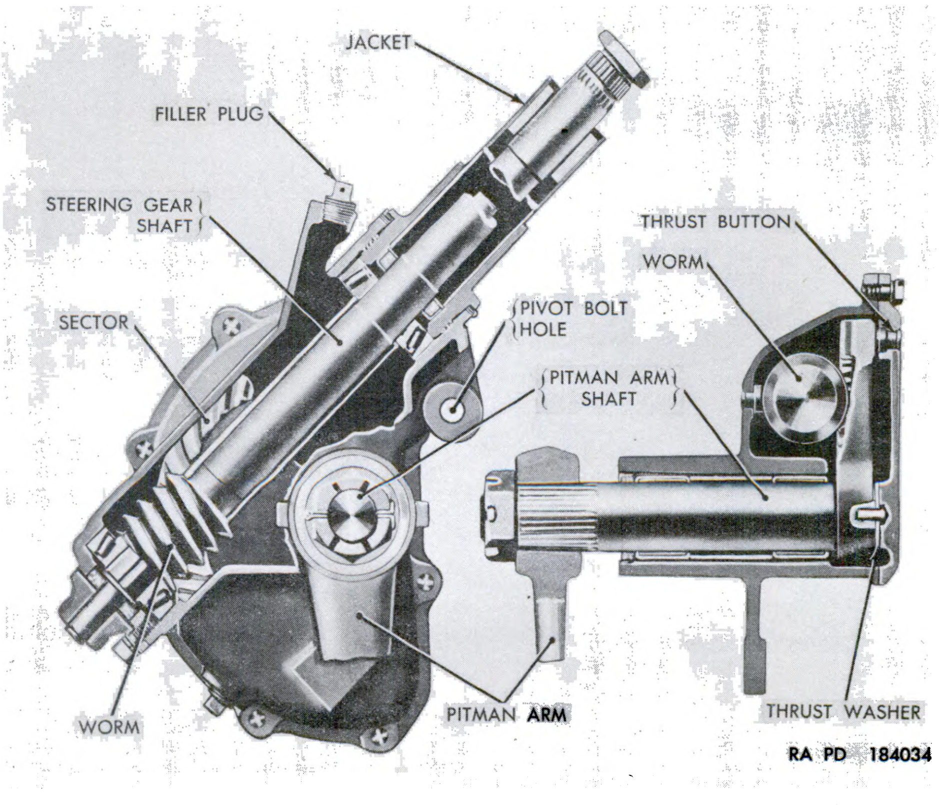

JACKET
FILLER PLUG
STEERING GEAR SHAFT
SECTOR
PIVOT BOLT HOLE
PITMAN ARM SHAFT
THRUST BUTTON
WORM
WORM
PITMAN ARM
THRUST WASHER
RA PD 184034

Figure 471. Variation of worm-and-sector steering gear.

tional losses. As the worm turns under control of the steering wheel, the roller turns with it but forces the sector and the pitman arm shaft to rotate.

b. The hourglass form of worm, that is, tapering from both ends to the center, affords better contact between the worm and roller at all positions. It provides a variable ratio to permit faster and more efficient steering. Variable ratio means that the ratio is larger at one position than another and therefore the road wheels are turned faster at certain positions than at others. At the center or straightahead position, the steering gear ratio is high, giving more mechanical advantage. However, as the wheels are cramped or turned to the side, the ratio decreases so that the action is much more rapid. This design is very helpful for parking or for maneuvering the vehicle.

266. Cam-and-Lever Steering Gear

a. A cam-and-lever steering gear, in which the worm is known as a cam, is shown in figure 473. The pitman arm shaft carries a lever on the inner end. This lever carries a stud which engages with the cam. The stud may be integral or mounted on roller bearings. Roller bearings re-

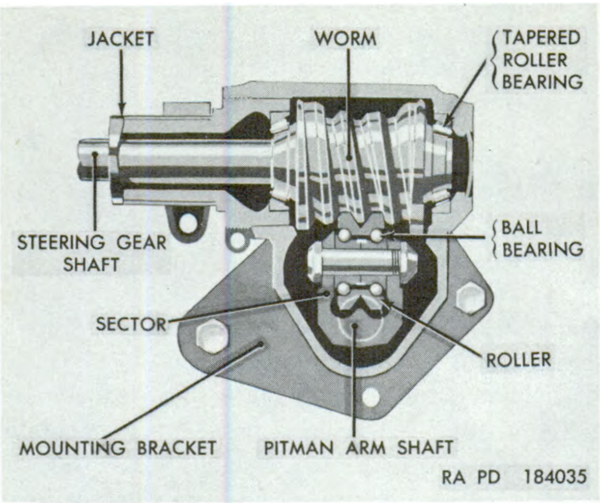

JACKET
WORM
TAPERED ROLLER BEARING
STEERING GEAR SHAFT
BALL BEARING
SECTOR
ROLLER
MOUNTING BRACKET
PITMAN ARM SHAFT
RA PD 184035

Figure 472. Worm-and-roller steering gear.

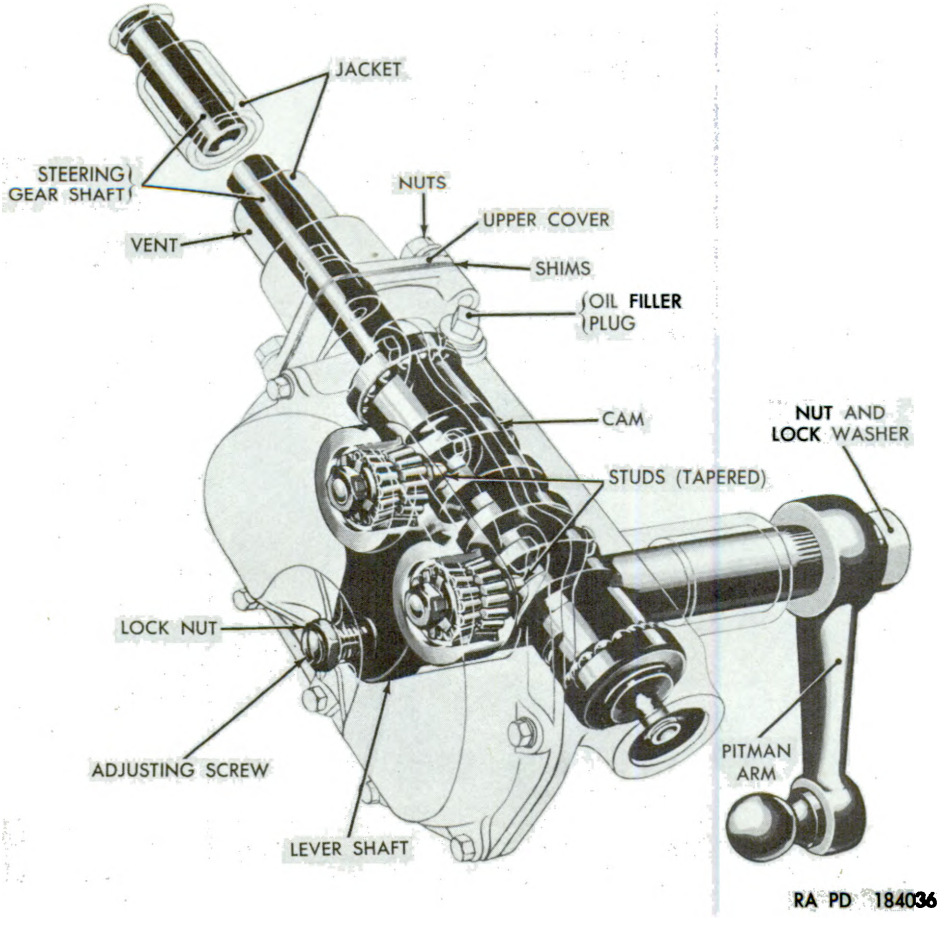

JACKET
STEERING GEAR SHAFT
NUTS
UPPER COVER
VENT
SHIMS
OIL FILLER PLUG
CAM
NUT AND LOCK WASHER
STUDS (TAPERED)
LOCK NUT
ADJUSTING SCREW
PITMAN ARM
LEVER SHAFT
RA PD 184036

Figure 473. Cam-and-twin-lever steering gear.

duce friction and allow easier steering. As the steering wheel is turned, the stud moves up and down on the cam and carries the lever with it to rotate the pitman arm shaft.

b. The lever moves more rapidly as it nears either end of the cam, since it is then at a greater angle with it. Maximum leverage occurs at the straightahead position when the lever is at right angles to the cam. This makes the initial turning of the wheels easier. It is seen, therefore, that a variable ratio is obtained with cam-and-lever steering. A twin lever provided with two studs (fig. 473) is used on a recent design for heavier vehicles, to obtain more stable and positive steering.

267. Worm-and-Nut Steering Gear

a. Another form of steering gear is the worm and nut, which is made in several different combinations. A nut is meshed with the worm and screws up and down on it. The nut may operate the pitman arm directly through a lever, or through a sector on the pitman arm shaft.

b. An example of the recirculating ball type of the worm-and-nut steering gear is shown in figure 474. In this steering gear, the nut, which is in the form of a sleeve block, is mounted on a continuous row of balls on the worm to reduce friction. This ball nut is fitted with tubular ball guides to return the balls diagonally across the nut to recirculate them as the nut moves up and down

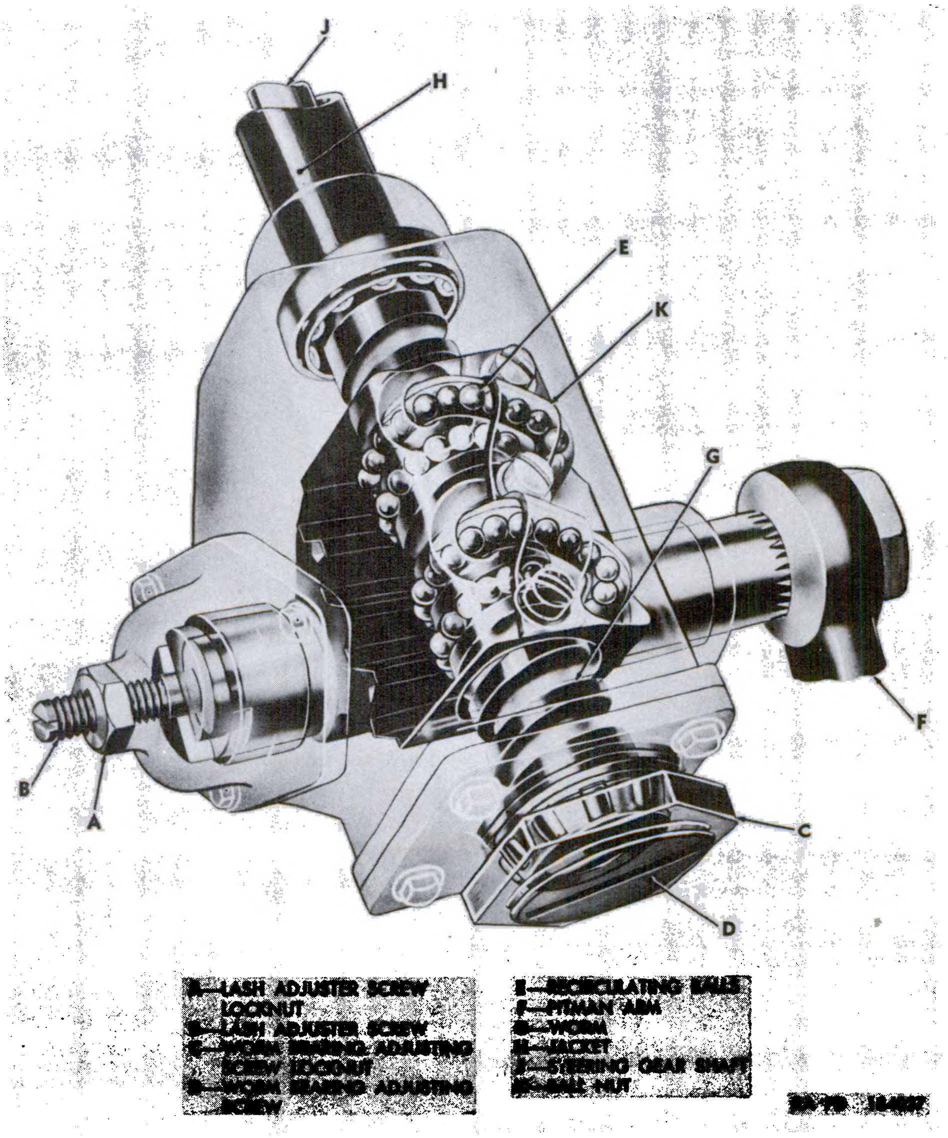

J
H
E
K
G
F
B
A
C
D
A—LASH ADJUSTER SCREW LOCKNUT
B—LASH ADJUSTER SCREW
C—WORM BEARING ADJUSTING SCREW LOCKNUT
D—WORM BEARING ADJUSTING SCREW
E—RECIRCULATING BALLS
F—PITMAN ARM
G—WORM
H—JACKET
J—STEERING GEAR SHAFT
K—BALL NUT
RA PD [illegible]

Figure 474. Worm-and-nut steering gear (recirculating ball type).

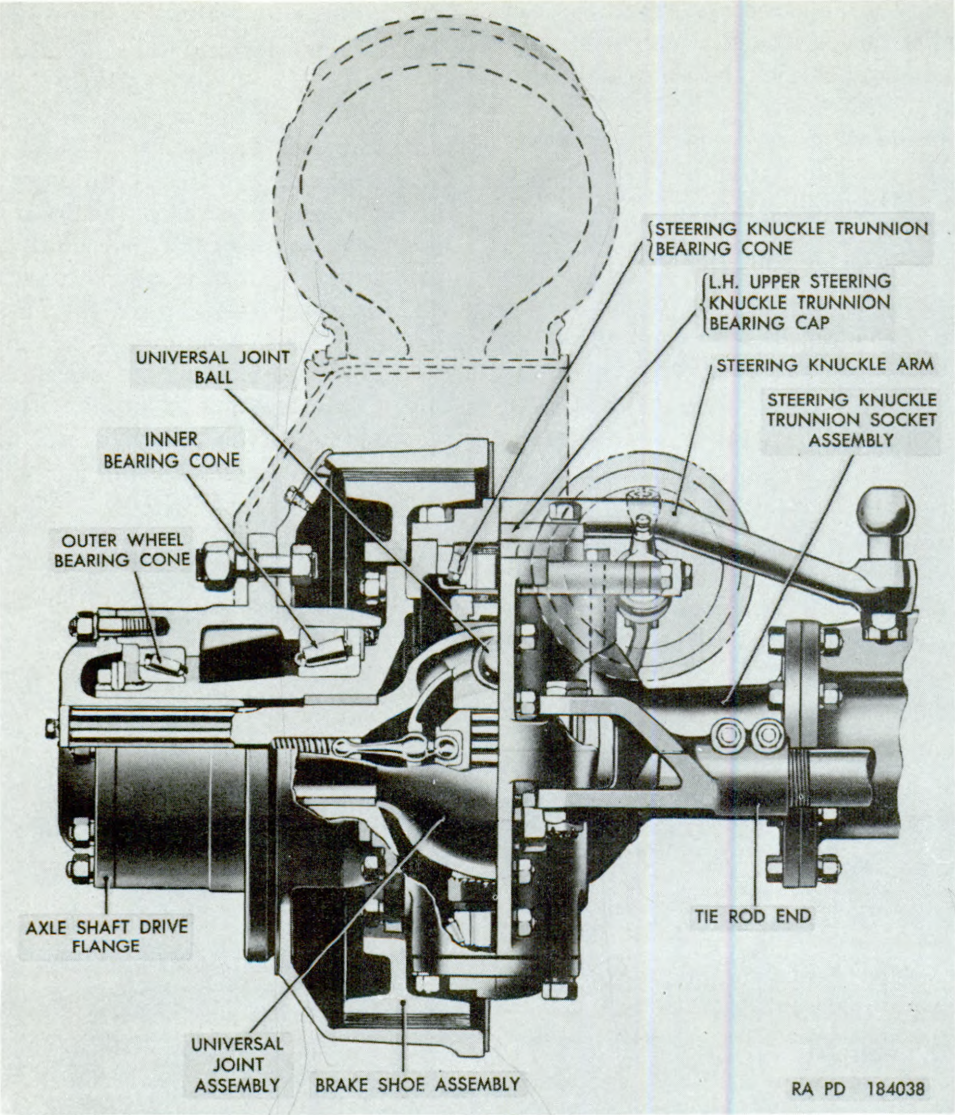

STEERING KNUCKLE TRUNNION BEARING CONE
L.H. UPPER STEERING KNUCKLE TRUNNION BEARING CAP
UNIVERSAL JOINT BALL
STEERING KNUCKLE ARM
STEERING KNUCKLE TRUNNION SOCKET ASSEMBLY
INNER BEARING CONE
OUTER WHEEL BEARING CONE
AXLE SHAFT DRIVE FLANGE
TIE ROD END
UNIVERSAL JOINT ASSEMBLY
BRAKE SHOE ASSEMBLY
RA PD 184038

Figure 475. Axle end construction for a wheel that both drives and steers.

on the worm. With this design, the nut is moved on the worm by rolling instead of by sliding contact. Turning the worm moves the nut and forces the sector and the pitman arm shaft to turn.

268. Four-Wheel Driving and Steering

a. Four-wheel drive, a construction in which all four wheels of the vehicle drive (and sometimes steer), is used on many military vehicles. A typical construction for a wheel that drives and steers is illustrated in figure 475. A universal joint is used at the end of the axle shaft so that the wheel will be free to pivot at the end of the axle, as well as be driven through the axle. The end of the axle housing incloses this universal joint and is provided with vertical trunnion pins that act as a steering knuckle pivot. The wheels, mounted on steering knuckles attached to these trunnion pivots, are free to turn about the pivots at the same time that they are driven through universal joints on the inner axle shaft. Steering knuckle arms are mounted on the steering knuckles so that the wheels can be turned about the trunnion steering knuckle pivots by the steering linkage.

b. All four wheels can be steered from the steering wheel by connecting the steering linkage of these wheels to the pitman arm. The rear wheels are connected together by knuckle arms and a tie rod so that the steering linkage for both

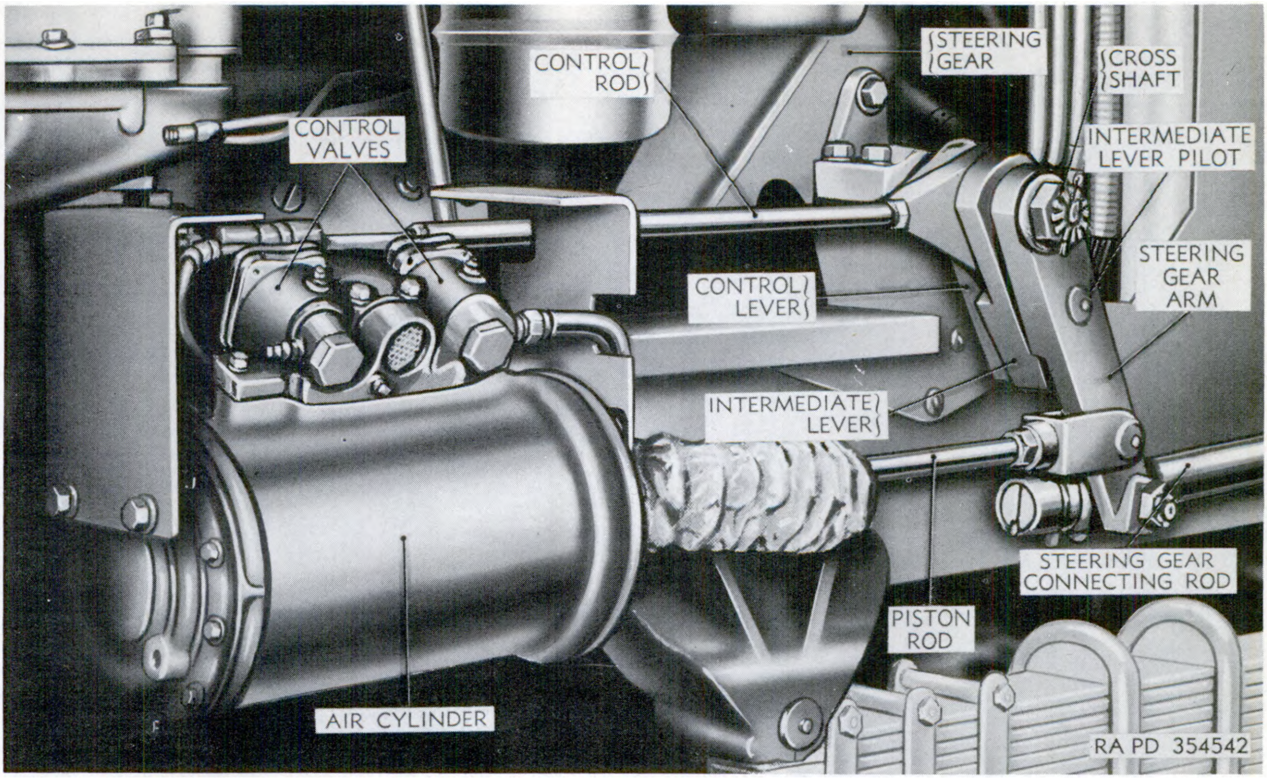


Figure 476. Air-steering control.

the front and rear wheels is similar to that described in paragraph 260*a* for 2-wheel steering. Since the rear wheels must be turned in the opposite direction to the front wheels to travel in the same arcs about the center of rotation, the drag links to the front and rear wheel steering linkage cannot be directly connected to the steering gear arm. The drag link to the front wheels must move forward while the drag link to the rear wheels moves rearward, and vice versa. To accomplish this, an intermediate steering gear arm is pivoted on the frame side member near the middle of the vehicle. The drag links are connected to opposite ends of this arm so that, as it is turned by direct connection to the pitman arm (by means of an intermediate drag link), the front and rear drag links are moved in opposite directions.

269. Air Steering

a. Heavy vehicles are difficult to steer because large loads on the tires increase their turning resistance. This difficulty cannot be overcome satisfactorily by using a steering gear with a very high reduction ratio, because it would require numerous revolutions of the steering wheel to turn the vehicle wheels. Some form of power steering to aid the driver in steering the heavier vehicles is therefore desirable. Air steering is a very satisfactory method of power steering, because the heavier vehicles on which it would be used usually have an air-braking system from which the air pressure can be obtained. If there is no air-braking system, an air compressor and reservoir are required to obtain the necessary air pressure.

b. Air-steering control (fig. 476) consists primarily of three major units: a combination of levers mounted on the steering gear pitman arm shaft; two control valves; and an air cylinder containing a double-acting piston. The control valves are mounted directly on the air cylinder, each valve controlling one side of the cylinder. The air pressure delivered from the air line to the cylinder is proportional to the force applied on top of the valve piston plunger by the control rod (fig. 477). The valves are actuated by a rocker arm so that air is delivered to one side of the cylinder at a time. These valves are so adjusted that the air can be exhausted from both sides of the cylinder simultaneously, but air pressure can be delivered to only one side at a time.

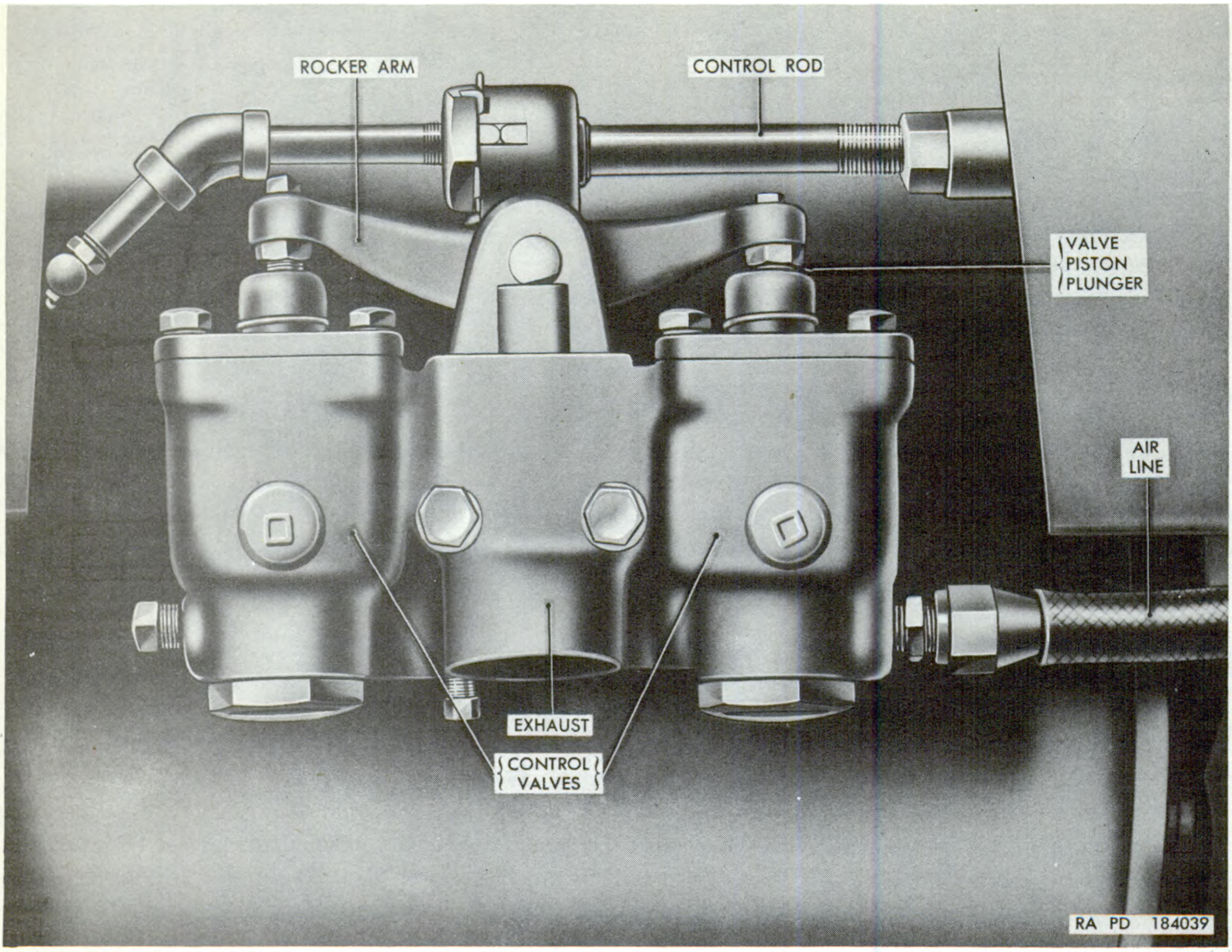


Figure 477. Top view of air cylinder control valves.

c. Three levers (fig. 476) are mounted on the pitman arm shaft: the control lever, the intermediate lever, and the pitman arm. The control lever is fixed directly to the pitman arm shaft. The intermediate lever is pivoted near its center to the pitman arm and at its lower end to the control lever. The upper end of the intermediate lever is bored slightly larger than the cross shaft, so that free motion is obtained, and is connected by a yoke to the control rod. The drag link is connected to the end of the pitman arm, and the cylinder piston rod is connected just above it.

d. Turning the steering wheel turns the pitman arm shaft and rotates the control lever in one direction or the other. If the control lever is moved to the right, the upper end of the intermediate lever, which is free, moves to the left because the intermediate lever is pivoted on the pitman arm. This causes the control rod to move to the left and, through the rocker arm (fig. 477), to exert pressure on the plunger of the left control valve, which is connected to the left side of the cylinder. Air under pressure will be admitted to the cylinder until the force on the piston in the cylinder is equivalent to the turning resistance of the wheels, and will move the piston rod to force the pitman arm to the right. As long as the steering wheel is turned, the valve will remain open. When the steering wheel stops turning, the piston continues to travel until the upper end of the intermediate lever shifts the control rod to the right and closes the left control valve, thereby cutting off any additional flow of air. The right control valve is operated in a similar manner when the control lever is rotated to the left and admits air

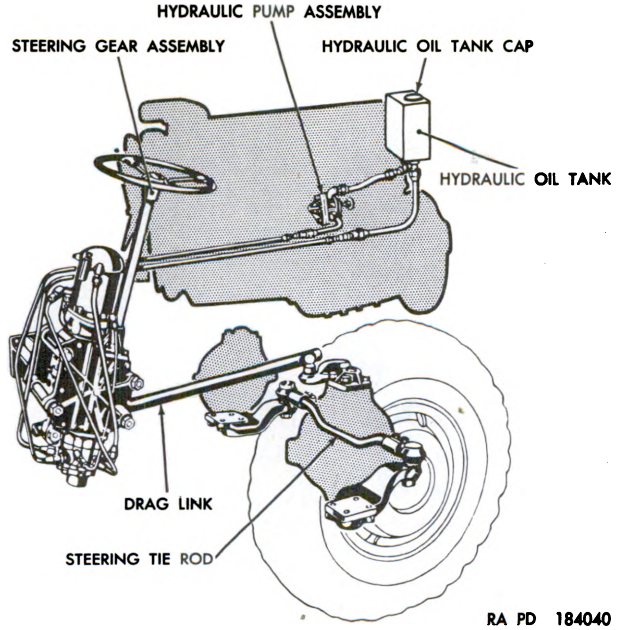


Figure 478. Hydraulic steering system—schematic view.

to the right side of the piston, thereby moving the pitman arm to the left.

e. Air-steering control reduces road shock and the tendency of the wheels to shimmy, because operation of the control valves is reversed by a very slight movement of the drag link. The driver, in steering, must overcome a certain resistance predetermined by the system of levers and exactly proportional to the angle of turn. If the air pressure fails, the wheels can still be steered by physical effort.

270. Hydraulic Steering System

(fig. 478)

The hydraulic steering system consists of a hydraulic cylinder, with piston secured to the top of the steering gear housing, and a hydraulic control valve secured to the bottom of the steering gear housing. The hydraulic portion of the system contains a hydraulic oil reservoir, secured to the inside of the rear engine cover and connected by oil lines to a hydraulic pump located on the left side of the engine and driven by the engine sprocket chain. The hydraulic pump delivers the oil under pressure to the hydraulic control valve. A bypass is provided in the pump so that oil is bypassed if it is not required at the control valve. If the steering wheel is turned to the right, or to the left, the hydraulic system comes into operation automatically and is of great assistance to the operator in turning the vehicle. This is accomplished by piping the oil, under pressure, from the control valve to the hydraulic cylinder where it actuates the piston which applies pressure on the steering gear levers. Whenever effort at the steering wheel is released, the oil pressure becomes balanced and the hydraulic system is inoperative, causing the oil again to be bypassed at the pump.

271. Power Steering

a. General. The term *power steering* has become well known in the automotive field since the introduction of hydraulic steering systems on various passenger cars. While there are variations in the different systems used on the different passenger cars, the description in *b* through *e* below, of the steering system used on some cars will serve, in a general way, to explain how these systems function.

b. Construction. The power-steering unit is located at the lower end of the steering column in place of the conventional steering gear, and is connected by two oil lines to the hydraulic pump mounted on the generator as shown in figure 479. The pump is of the conventional rotor type with a relief valve to prevent excessive oil pressures. The power-steering unit consists of a valve body with four valves and two power cylinders with pistons, one on each side of a piston arm, attached to the steering shaft (fig. 480). In operation, the valves direct oil to the piston that will assist in making a turn as explained in *c* through *e* below.

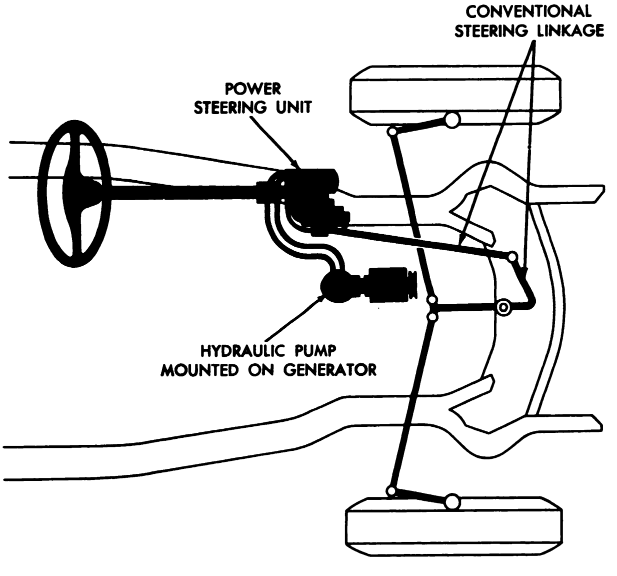

CONVENTIONAL STEERING LINKAGE
POWER STEERING UNIT
HYDRAULIC PUMP MOUNTED ON GENERATOR
RA PD 184041

Figure 479. Location of power-steering unit.

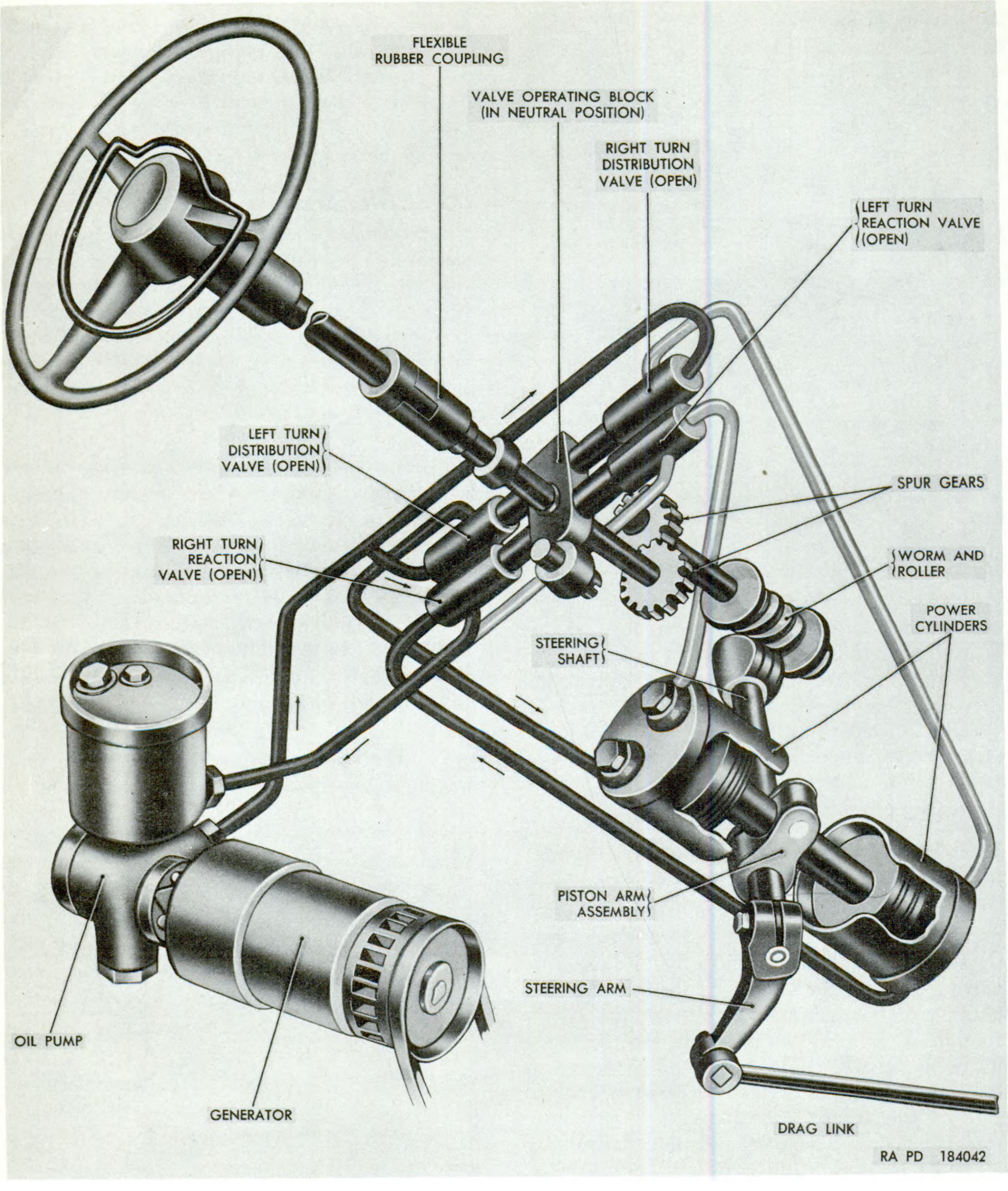

FLEXIBLE RUBBER COUPLING
VALVE OPERATING BLOCK (IN NEUTRAL POSITION)
RIGHT TURN DISTRIBUTION VALVE (OPEN)
LEFT TURN REACTION VALVE (OPEN)
LEFT TURN DISTRIBUTION VALVE (OPEN)
SPUR GEARS
RIGHT TURN REACTION VALVE (OPEN)
WORM AND ROLLER
POWER CYLINDERS
STEERING SHAFT
PISTON ARM ASSEMBLY
STEERING ARM
OIL PUMP
GENERATOR
DRAG LINK
RA PD 184042

Figure 480. Power-steering system in neutral, or in straight-ahead position (valves are open, preventing pressure buildup in either power cylinder).

c. Operation. A valve-operating block in the valve body is mounted on the lower end of the steering column. The lower section of the 2-piece steering column is mounted in a spherical bearing to permit the lower section of the steering column to pivot slightly in this bearing. This movement permits the steering column spur gear (at the extreme lower end of the column) to move several thousandths of an inch with respect to the spur gear on the worm shaft. When the steering wheel is turned one way or the other, the resulting torque on the spur gears causes the steering column spur gear to climb up or down (a fraction of an inch) on the worm shaft spur gear. It is this movement that causes the valve-operating block to move one way or the other, closing one or the other pair of valves in the valve body.

d. Left Turn. For example, a left turn is made. As the steering wheel is turned to the left (fig. 481), the steering column spur gear climbs up the worm shaft spur gear. This action moves the valve-operating block up so that the right-turn distribution valve and the left-turn reaction valve are closed. At the same time, the left-turn distribution valve and the right-turn reaction valve remain open. Now, oil pressure from the hydraulic pump builds up in the left power cylinder through the left-turn distribution valve while oil pressure is released from the right power cylinder through the right-turn reaction valve, as shown in figure 481. The power pistons move as shown, applying pressure on the piston arm assembly. This provides hydraulically produced torque on the steering shaft, assisting in turning the shaft and, consequently, in the steering. As soon as turning effort on the steering wheel is eased off, the reaction between the two spur gears is reduced, the steering column spur gear assumes its midposition, and the valve-operating block assumes its midposition. In the straightahead position, as on a straight road, the steering system will be as shown in figure 480.

e. Right Turn. During a right turn, the steering column spur gear climbs down on the worm shaft spur gear, causing the valve-operating block to move downward, closing the two lower valves. Oil pressure therefore builds up in the right power cylinder, causing the piston arm assembly to move and assist the right turn.

f. Power-Steering System. Another power-steering system, shown schematically in figure 482, operates in a very similar manner; but it depends on an endwise movement of the steering-column shaft, rather than on a pivoting effect as with other systems. In this system, turning the steering wheel rotates the worm, imposing an endwise thrust on the worm. The endwise thrust is either up or down, depending on the direction of rotation. This endwise thrust causes the steering-column shaft to move endwise a small fraction of an inch. A valve that is integral with the shaft moves in a valve body. This action admits oil pressure in one or the other end of a power cylinder, causing a piston to move in one or the other direction. The motion is carried to the pitman shaft through a rack and gear sector, as shown. This system, as with the one described in *b* through *e* above, is designed to greatly reduce steering effort by supplying the major effort hydraulically.

g. Hydraulic-Steering System. Hydraulic steering gear, shown in place on the lower end of the steering column in figure 483, is very similar to the power-steering system described in *f* above. A valve or spool is centered in the hydraulic valve control assembly, which is mounted on the steering column. The spool is held in the centered position by means of a centering spring at each end. When a turn is made, there is endwise thrust on the steering column, and this causes the spool to move one way or the other in the control assembly. Figure 484 shows three positions of the spool, for left turn, for right turn, and for straight ahead. As the spool is shifted, it opens a port to one side of the power cylinder through which oil pressure is delivered to that side of the cylinder. At the same time, another port is opened to the other side of the power cylinder, which permits oil to flow from that side of the cylinder to the oil reservoir. As a result, the piston is moved in the power cylinder, assisting in steering.

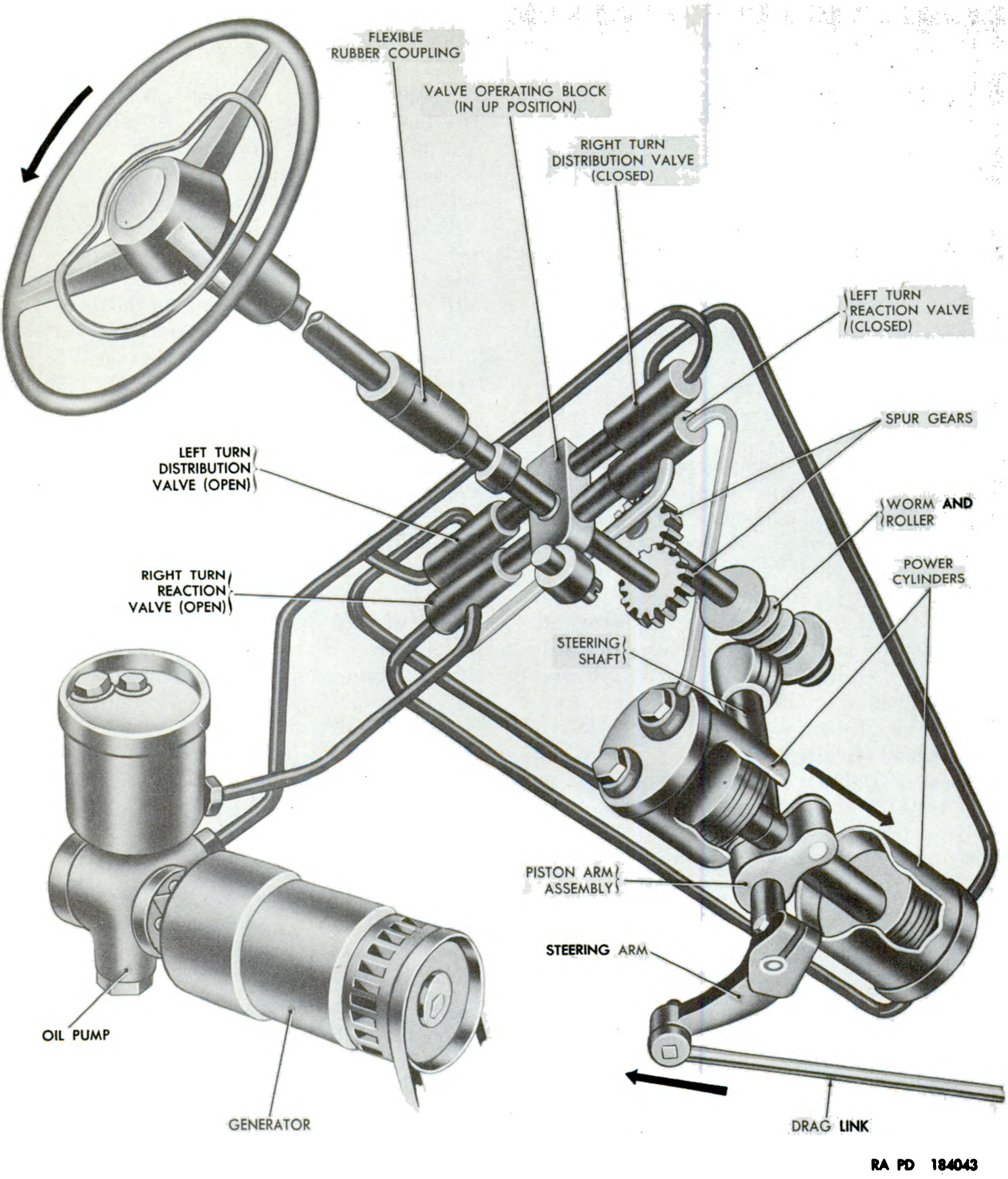

FLEXIBLE RUBBER COUPLING
VALVE OPERATING BLOCK (IN UP POSITION)
RIGHT TURN DISTRIBUTION VALVE (CLOSED)
LEFT TURN REACTION VALVE (CLOSED)
SPUR GEARS
WORM AND ROLLER
POWER CYLINDERS
LEFT TURN DISTRIBUTION VALVE (OPEN)
RIGHT TURN REACTION VALVE (OPEN)
STEERING SHAFT
PISTON ARM ASSEMBLY
STEERING ARM
OIL PUMP
GENERATOR
DRAG LINK
RA PD 184043

Figure 481. Power-steering system during a left turn.

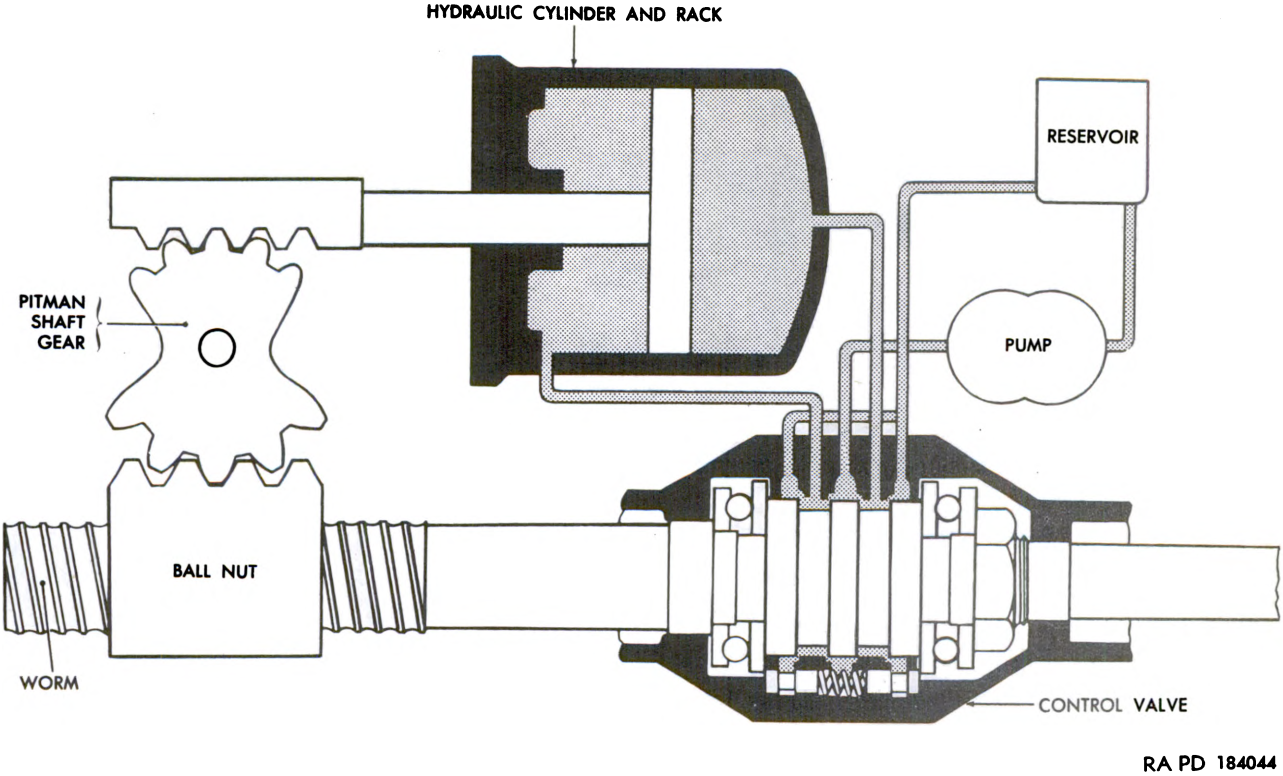

HYDRAULIC CYLINDER AND RACK
RESERVOIR
PITMAN SHAFT GEAR
PUMP
BALL NUT
WORM
CONTROL VALVE
RA PD 184044

Figure 482. Power-steering system.

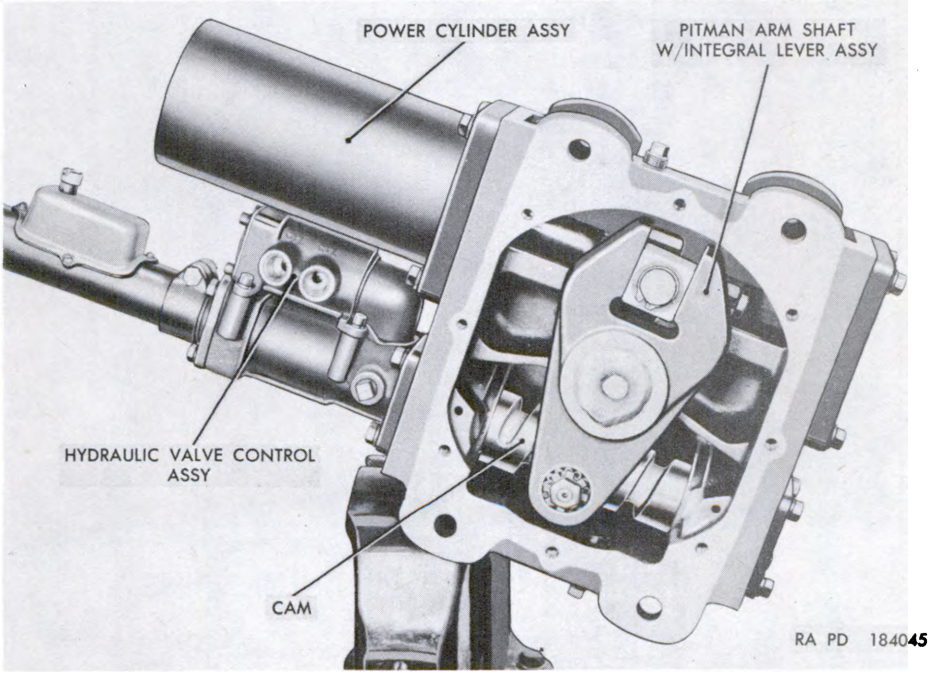

POWER CYLINDER ASSY
PITMAN ARM SHAFT W/INTEGRAL LEVER ASSY
HYDRAULIC VALVE CONTROL ASSY
CAM
RA PD 184045

Figure 483. Steering gear, with cover removed—right-side view.

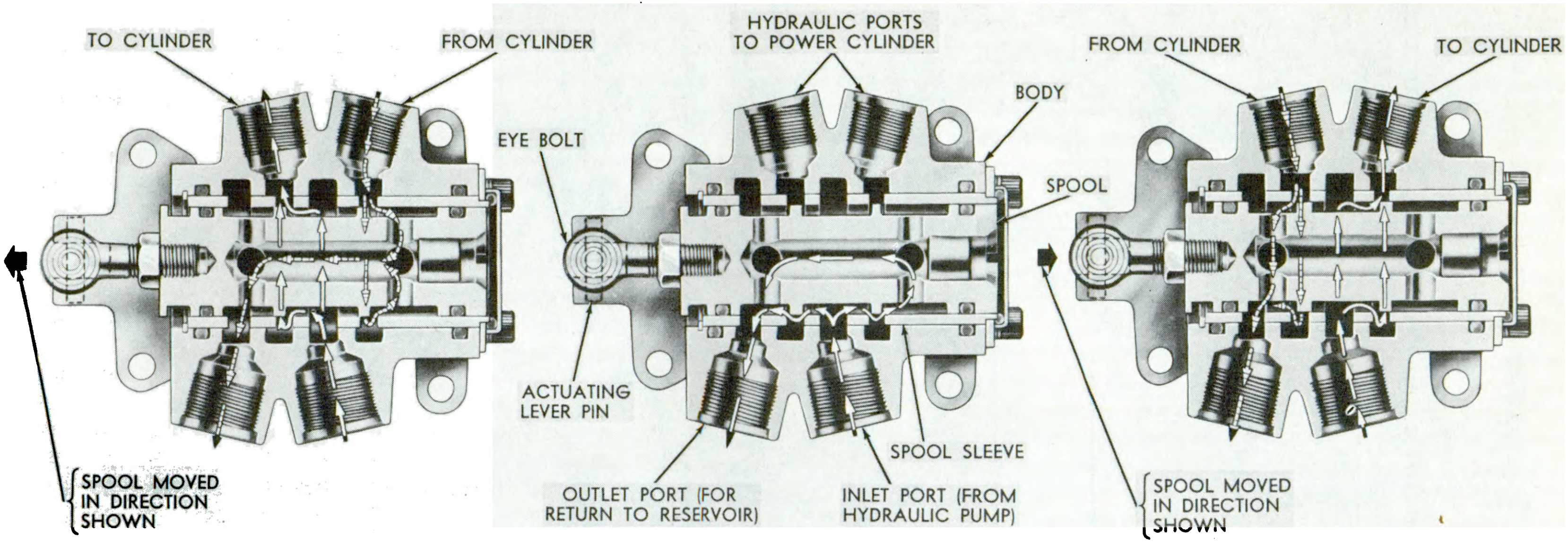

TO CYLINDER
FROM CYLINDER
SPOOL MOVED IN DIRECTION SHOWN
EYE BOLT
ACTUATING LEVER PIN
HYDRAULIC PORTS TO POWER CYLINDER
BODY
SPOOL
SPOOL SLEEVE
OUTLET PORT (FOR RETURN TO RESERVOIR)
INLET PORT (FROM HYDRAULIC PUMP)
FROM CYLINDER
TO CYLINDER
SPOOL MOVED IN DIRECTION SHOWN

FIG. C
FLUID FLOW WHEN SPOOL IS POSITIONED AS SHOWN ABOVE

FIG. A
NEUTRAL SPOOL POSITION AND FLUID FLOW

⇨ **FLUID FROM PUMP**
⇨ **DISPLACED FLUID FROM CYLINDER**

FIG. B
FLUID FLOW WHEN SPOOL IS POSITIONED AS SHOWN ABOVE

RA PD 135615

Figure 484. Hydraulic control valve, showing fluid flow in various spool positions—sectional views.

Section II. WHEEL ALINEMENT

272. General

a. Wheel alinement is the mechanics of keeping all the interrelated parts of the front wheels properly adjusted. This is done to prevent pulling to the right or left, scuffed tires, wander, shimmy, tramp, and hard steering.

b. The front-end assembly of the modern motor vehicle is one of the most remarkable engineering accomplishments on the entire vehicle. The steering linkage must be designed so the wheels will have the proper toe-out when turning. The steering knuckle pivots are castered or title backward and are also cambered or tilted inward, to give a steering knuckle pivot inclination. The wheels are cambered or tilted outward and are also toed-in at the front.

c. Five main factors listed in (1) through (5) below, all of them related and dependent upon each other, determine proper wheel alinement—

(1) Toe-out.
(2) Caster.
(3) Camber.
(4) Kingpin (pivot) inclination.
(5) Toe-in.

273. Steering Geometry

a. The front end assembly of the modern motor vehicle requires careful design and adjustment because each front wheel is separately pivoted on a steering knuckle (Ackerman steering, par. 259*b* and fig. 464). Because of this construction, the front wheels, when a vehicle is making a turn, are not on the same radius line, drawn from the center of rotation (top diagram, fig. 485). Since each wheel should be at right angles to its radius line, it is necessary for the front wheels to assume a toed-out position when rounding curves. If they do not, the tires slip, which causes excessive tire wear.

b. The manner in which toe-out on turns can be achieved is illustrated in the center and bottom diagrams in figure 485. In the center diagram, the steering arms are shown as being parallel to each other. With this arrangement, toe-out on turns could not be achieved, since the steering arms would travel over corresponding segments of arc as shown and the wheel spindles (and wheels) would therefore turn the same amount. However, if the knuckle arms are tilted toward each other as shown in the bottom diagram in figure 485, the steering arms will not travel over corresponding segments of arc and the two spindles (and wheels) will turn different amounts. The inner wheel (the one closer to the center of rotation) would turn more than the outer wheel so it will travel in a smaller radius. This difference in the turning ratios of the two wheels is termed *toe-out.* It is usually specified as the number of degrees over 20 which the inner wheel is turned when the outer wheel is turned 20°. For instance, it is 3° in the top diagram of figure 485.

c. Analysis of this linkage will show that even though the wheels are turned different amounts, they do not have an exactly common center of rotation. All steering designs are necessarily close approximations to the ideal condition. They attempt to bring the center of rotation of both wheels close to the vehicle's center of rotation under all turning conditions. The exact amount of inclination of the steering knuckle arms toward each other is very carefully studied on any particular design.

274. Caster

a. Caster is the angle, measured in degrees (fig. 486), that the steering knuckle pivots are tilted forward or backward from the vertical when viewed from the side. Caster tends to keep the front wheels pointed straightahead, making it easy to return the wheels to a straight-ahead position after a turn has been made. The principle is exactly the same as that used in tilting the front fork of a bicycle, which makes it possible to ride the bicycle without grasping the handlebars. Part of the effort applied for turning castered wheels out of the straightahead position slightly raises the front end of the vehicle upward. Consequently, when the steering gear is released, the weight of the vehicle forces the front end down and straightens the wheels. Caster is designated as *positive* for backward tilt and *negative* for forward tilt of the steering knuckle pivots.

b. With axle suspension, caster may be obtained by inserting a thin wedge or shim between the axle and the spring. The axle can be made so that the supports for the steering knuckle pivots are tilted from the vertical. In parallel arm suspension, caster is obtained by mounting the steering knuckle support in the control arms

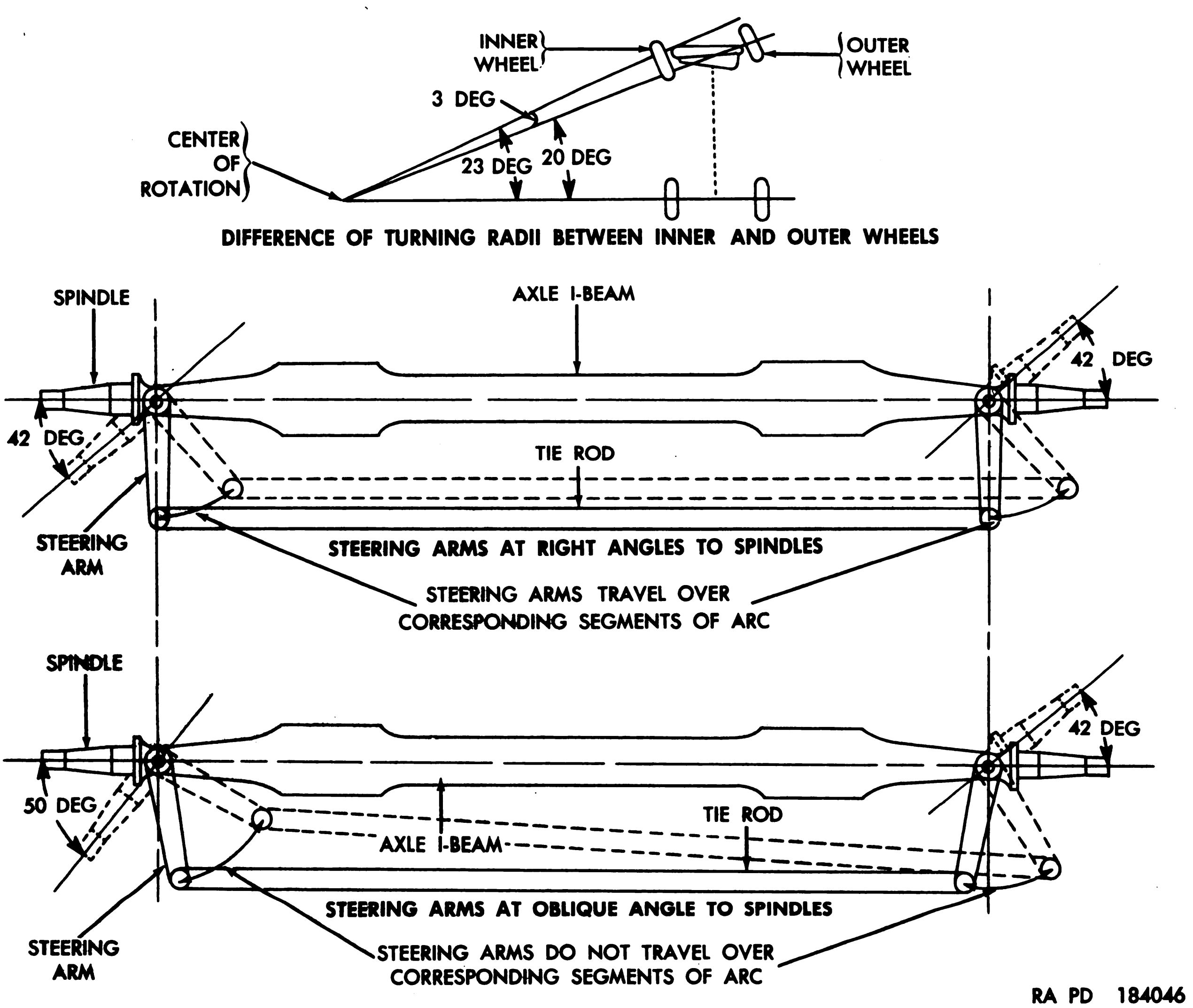

INNER WHEEL
OUTER WHEEL
3 DEG
CENTER OF ROTATION
23 DEG
20 DEG
DIFFERENCE OF TURNING RADII BETWEEN INNER AND OUTER WHEELS
SPINDLE
AXLE I-BEAM
42 DEG
42 DEG
TIE ROD
STEERING ARM
STEERING ARMS AT RIGHT ANGLES TO SPINDLES
STEERING ARMS TRAVEL OVER CORRESPONDING SEGMENTS OF ARC
SPINDLE
42 DEG
50 DEG
TIE ROD
AXLE I-BEAM
STEERING ARMS AT OBLIQUE ANGLE TO SPINDLES
STEERING ARM
STEERING ARMS DO NOT TRAVEL OVER CORRESPONDING SEGMENTS OF ARC
RA PD 184046

Figure 485. Steering geometry, illustrating toe-out.

so that it is tilted the desired amount. If the axis of the steering knuckle pivot is extended, it must strike the ground ahead or behind the point where the tire meets the ground. The caster varies from one-half to 3° on modern vehicles.

275. Camber

Wheel camber (fig. 487) is the angle made by the wheel with the vertical when it is in the straightahead position. Cambered wheels are closer together at the bottom than they are at the top. For many years, front-wheel camber as great as 3° has been used. For driving on crowned roads, this camber permitted better rolling contact by bringing the wheel perpendicular to the road and made steering easier. In recent years, the use of flat roads and low pressure tires has lead to a decrease in camber. If the vehicle were

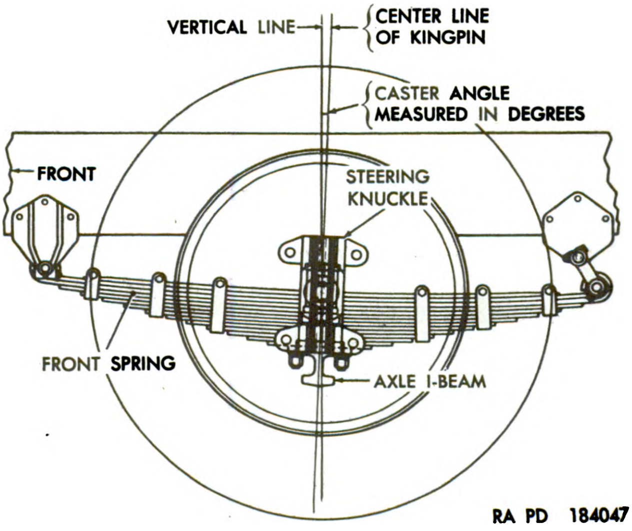

VERTICAL LINE
CENTER LINE OF KINGPIN
CASTER ANGLE MEASURED IN DEGREES
FRONT
STEERING KNUCKLE
FRONT SPRING
AXLE I-BEAM
RA PD 184047

Figure 486. Positive caster.

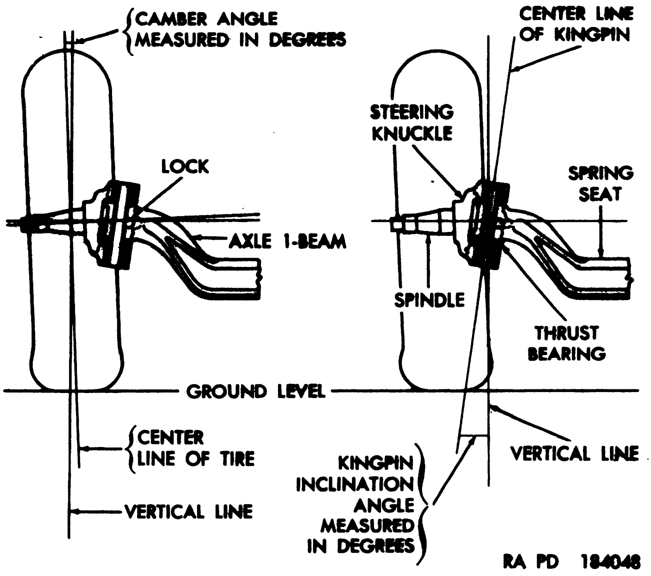

CAMBER ANGLE MEASURED IN DEGREES
CENTER LINE OF KINGPIN
STEERING KNUCKLE
LOCK
SPRING SEAT
AXLE I-BEAM
SPINDLE
THRUST BEARING
GROUND LEVEL
CENTER LINE OF TIRE
VERTICAL LINE
KINGPIN INCLINATION ANGLE MEASURED IN DEGREES
VERTICAL LINE
RA PD 184048

Figure 487. Camber and kingpin inclination.

run on a flat road and had no lost motion at the bearings, zero camber would be ideal; but it is not practical to build front axles with zero camber because of the possible accumulation of bearing clearances and the slight deflection of the axle under the vehicle load. Therefore, a camber of about 1° is recommended at present. Excessive camber causes continual slippage of the tire on the road, because each wheel tries to follow a path away from that traveled by the vehicle. This is due to the fact that a cambered wheel tends to roll like a cone because its axis is not horizontal.

276. Kingpin Inclination

a. Kingpin, or pivot, inclination is the amount in degrees (fig. 487), that the steering knuckle pivots are tilted sideways toward the center of the vehicle. Inclination of the steering knuckle pivots tends to keep the wheel spindles pointed outward in line with the axle, just as caster tends to keep the wheels of a vehicle pointed straight-ahead. The effect is the same and will also result in easier steering.

b. Setting the steering knuckle pivot at an angle causes the pivot axis to meet the ground close to the center of the tire contact (fig. 487). The wheel, therefore, has a small turning radius so that it will be easy to turn and will roll in a very small arc on the ground. Too much inclination makes it difficult to park a vehicle because, if the intersection of the pivot axis to the ground falls at the center of tire contact with the ground, the tire slides rather than rolls when the wheel is turned on a stationary vehicle. Pivot inclination is usually from 3° to 7°.

c. Careful distinction should be made between camber and kingpin inclination (fig. 487). They are closely related and dependent on each other. Wheels with large camber require large kingpin inclination and those with small camber require small kingpin inclination. Pivot inclination allows the front wheel brakes to be applied with little effect on steering.

277. Toe-In

(fig. 488)

a. Toe-in is the amount in inches that the wheels point in; that is, the distance between the front wheels is less at the front (A, fig. 488) than it is at the rear (B, fig. 488). Toe-in and camber are definitely related and depend on the crown of the road. For a flat road, experience indicates that a desirable condition is to have zero camber and zero toe-in. However, such a condition is difficult to maintain.

b. Toe-in balances the effect of camber on the tires. A cambered wheel is not vertical to a flat road, and the axis of the wheel, if prolonged, will intersect the road at some point to the side of the vehicle. The natural tendency of the wheel

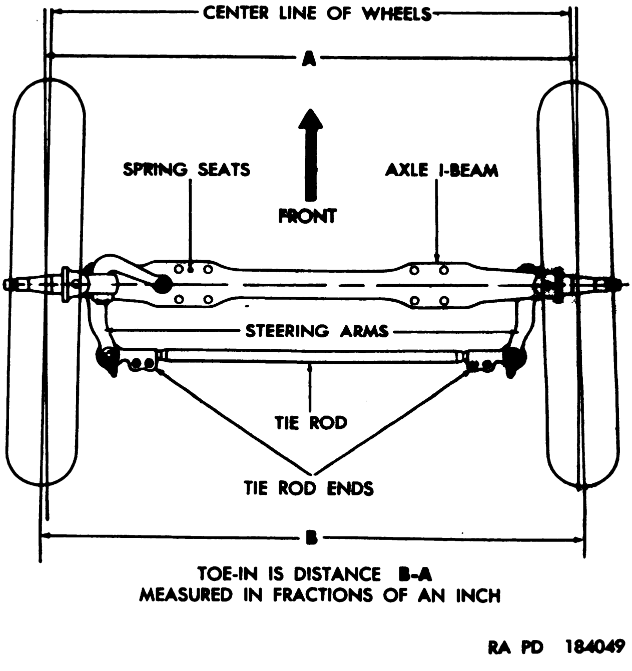

CENTER LINE OF WHEELS
A
SPRING SEATS
FRONT
AXLE I-BEAM
STEERING ARMS
TIE ROD
TIE ROD ENDS
B
TOE-IN IS DISTANCE B-A
MEASURED IN FRACTIONS OF AN INCH
RA PD 184049

Figure 488. Toe-in.

is to rotate like a cone about this point. If both front wheels are forced to follow a straight path by the motion of the vehicle, there is a continual tendency for tires to slip away from each other. Toed-in wheels tend to travel toward each other and counteract this condition. By properly relating camber and toe-in, tire wear is reduced to a minimum, the motion of the wheel is balanced between two opposing tendencies, and pull on the steering mechanism is reduced. The amount of toe-in is adjustable by changing the length of the tie rod.

CHAPTER 21

BRAKES

Section I. PRINCIPLES

278. Action

Braking action is the use of a controlled force to reduce the speed of, or stop, a moving vehicle; or to keep a vehicle stationary. When the braking force is applied, it develops friction, which does the braking. Friction is the resistance to relative motion between two surfaces in contact. Thus, by forcing a stationary surface into contact with a moving surface, the resistance to relative motion or the rubbing action between the two surfaces will slow down the moving surface. Automotive vehicles are braked in this manner. Braking action may also be accomplished by establishing a rubbing contact with the roadway, as is done by some trolleys which apply a braking surface to the rails.

279. Requirement

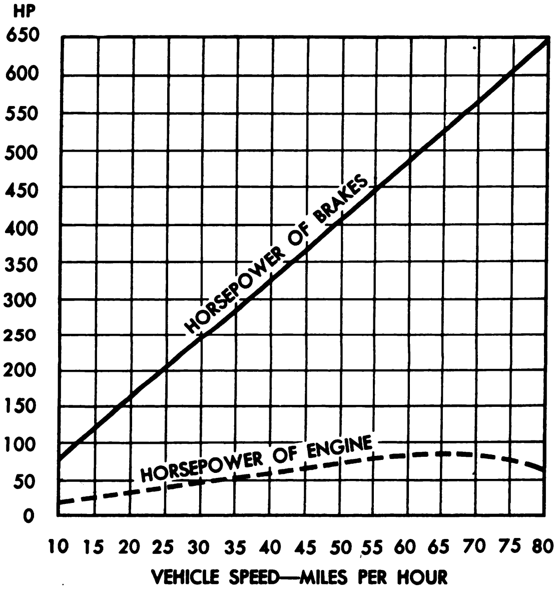
a. It is generally known that to increase a vehicle's speed requires an increase in the power output of the engine. It is equally true, although not so apparent, that an increase in speed requires an increase in the braking action necessary to bring a vehicle to a stop. A moving vehicle, just as any other moving body, has what is known as *kinetic energy.* This kinetic energy, which increases with the square of the speed, must be overcome by braking action. If the speed of a vehicle is doubled, its kinetic energy is increased fourfold; four times as much energy must therfore be overcome by the braking action.

b. Brakes must not only be capable of stopping a vehicle, but must stop it in as short a distance as possible. Because brakes are expected to decelerate a vehicle at a faster rate than the engine can accelerate it, they must be able to control a greater power than that developed by the engine. This is the reason that well-designed, powerful brakes have to be used to control the modern high-speed motor vehicle. A comparison between the horsepower developed by the engine and the horsepower controlled by the brakes of a passenger car is shown in figure 489.

c. It is possible to accelerate an average passenger car with an 80-hp engine from a standing start to 80 mph in 36 seconds. By applying the full force of the brakes, such a vehicle can be decelerated from 80 mph to a full stop in 4.5 seconds. The time required to decelerate to a stop is one-eighth the time required to accelerate from a standing start; hence, the brakes handle eight times the power developed by the engine. Thus, about 640 (8x80) hp has to be expended by the friction surfaces of the brakes of an average passenger car to bring it to a stop from 80 mph in 4.5 seconds.

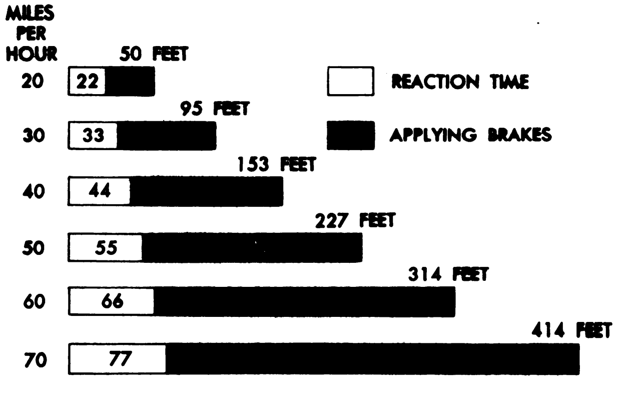
280. Vehicle Stopping Distance

Driver reaction time is an important factor in applying the brakes and stopping a vehicle. This is the time required for the driver to apply the



RA PD 184050

Figure 489. Comparison of engine horsepower and required horsepower of brakes.



RA PD 184051

Figure 490. Total vehicle stopping distance.

brakes and to move his foot to the brake pedal. During the time that the driver is thinking of applying the brakes and moving his foot to do so, the vehicle will move a certain distance, depending on its speed. After the brakes are applied, the vehicle will travel an additional distance before it is brought to a stop. Total stopping distance of a vehicle is the total of the distance covered during the driver's reaction time and the distance during which brakes are applied before the vehicle stops. Figure 490 gives total stopping distance required at various vehicle speeds, assuming an average reaction time of three-quarter second and that good brakes are applied under most favorable road conditions.

281. Factors Affecting Retardation

a. The amount of retardation obtained by the braking system of a vehicle is affected by several factors. For wheel brakes used on motor vehicles, these factors are listed in (1) through (6) below.

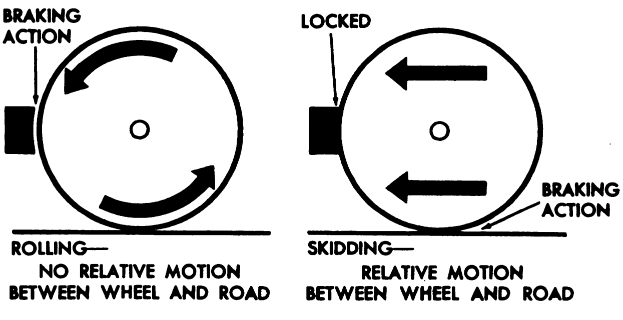
(1) Pressure exerted on braking surfaces (lining and drum).
(2) Weight carried on wheel.
(3) Overall radius of wheel (distance from center of wheel to outer tread of tire).
(4) Radius of brakedrum (rotating member).
(5) Coefficient of friction between braking surfaces.
(6) Coefficient of friction between tire and road.

b. For a definite amount of retardation, exerted pressure required on braking surfaces will become greater when weight carried on the wheel or overall radius of the wheel is increased. These factors are independent of the design of the braking system and generally are a fixed value. However, limitations of these factors, particularly the weight of the vehicle to be carried by the wheels, must be considered when designing a braking system. If the radius of the brake drum or coefficient of friction between the braking surfaces is increased, less pressure will be required to obtain the same degree of retardation. The best results are obtained when these factors are correlated within the limits permitted by the design of the braking system. The coefficient of friction between tire and road determines maximum retardation obtained by the application of brakes.

282. Maximum Retardation Point

a. When brakes are applied, the wheel will either roll or skid, depending on relative values of coefficients of friction between braking surfaces and between tire and road. Heavy jamming of the braking surfaces together will tend to increase the friction to such a degree that the wheel will lock. When this happens, braking action is caused by friction between tire and road, which heats and wears the tire.

b. Maximum retardation is reached when friction between the brake surfaces is such that the wheel is about to lock. At this point, friction between the brake surfaces is almost the same as that between tire and road. This is the maximum amount of friction that can be used in retarding motion of the vehicle. Friction encountered between tire and road is the limiting factor of braking. Should friction between braking surfaces go beyond this, the braking surfaces will lock and the wheel will skid. The action produced when a wheel rolls and when it skids is shown in figure 491. When a wheel rolls along a road, there is no relative motion at the point the tire makes contact with the road because the wheel rolls with the road surface, but when a



RA PD 184052

Figure 491. Action produced when wheel rolls or skids.

wheel skids, there is relative motion at the point of contact because the wheel is not rotating while moving over the road surface. When a wheel skids, friction is reduced, which decreases the braking effect. Nevertheless, brakes are designed so that the vehicle operator is able to lock the wheels if he applies enough force on the foot pedal.

Section II. MECHANISMS

283. Rotating and Nonrotating Units

Brake mechanisms may be of various designs, but they all require a rotating unit and a nonrotating unit, each containing one of the braking surfaces that are rubbed together to achieve the braking action. The rotating unit on motor vehicle wheel brakes consists of a drum secured to the wheel. The nonrotating unit consists of brakeshoes and linkage necessary to apply the shoes to the drum. Brakes are either of the external-contracting or internal-expanding type, depending on how the nonrotating braking surface is forced against the rotating braking surface.

284. External-Contracting Brake

a. When brakeshoes or a brake band is applied against the outside of the rotating brakedrum, the brake is known as an *external-contracting brake*, since the nonrotating braking surface must be forced inward around the drum to produce the friction necessary for braking. A brake using an external-contracting band is shown in figure 492. The brake band is tightened around the drum by moving the brake lever.

b. Unless an elaborate cover is provided, the external-contracting brake is exposed to dirt, water, and other foreign matter, which rapidly wears the lining and drum and destroys their frictional properties. This is particularly true with wheel brakes.

285. Internal-Expanding Brake

The nonrotating unit may be placed inside the rotating drum with the drum acting as a cover for the braking surfaces. This type of brake is known as an *internal-expanding brake* because the non-rotating braking surface is forced outward against the drum to produce braking action. A brake using internal-expanding shoes is shown in figure 493. This type of brake is used on the wheel brakes of the modern motor vehicle because it permits a more compact and economical construction. The brakeshoes and brake-operating mechanism may be conveniently mounted on a backing plate or brake shield made to fit against the open end of the brakedrum and thus protect the braking surfaces from dust and other foreign matter.

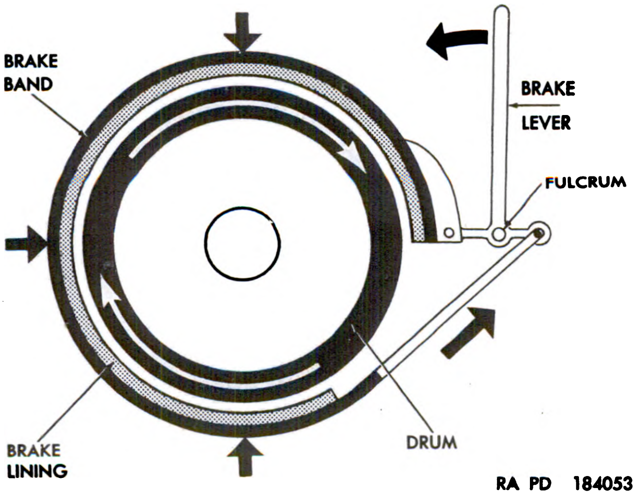


Figure 492. External-contracting brake.

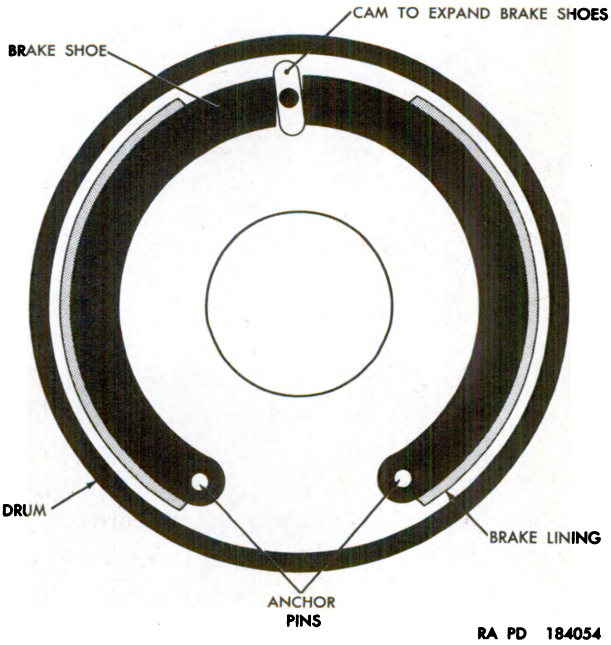


Figure 493. Internal-expanding brake.

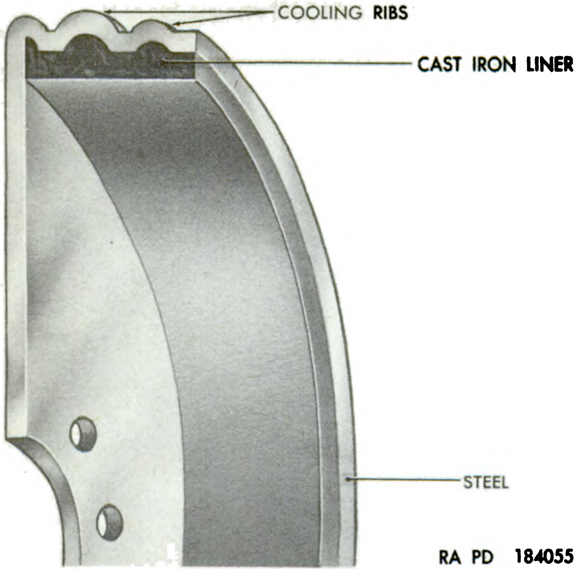


Figure 494. Centrifuse brakedrum.

286. Brakedrum

a. Brakedrums are made of pressed steel, cast iron, or a combination of the two metals. Cast-iron drums dissipate the heat generated by friction more rapidly than steel drums and have a higher coefficient of friction with any particular brake lining. However, cast-iron drums of sufficient strength are heavier than steel drums. To provide light weight and sufficient strength, centrifuse brakedrums (fig. 494) of steel with a cast-iron liner for the braking surface are used. A solid cast-iron drum of the same total thickness as the centrifuse drum would be too weak, while one of sufficient strength would be too heavy for the average passenger car. To give greater strength and better heat dissipation, cooling ribs are sometimes added to the outside of the drums.

b. Braking surfaces of drums may be ground or they may be smoothly machined to a finish. For good braking action the drum should be perfectly round and have a uniform surface. Brakedrums become "out-of-round" from pressure exerted by brakeshoes or bands and from heat developed by application of the brakes. The brakedrum surface becomes scored when it is worn by braking action. When the surface is badly scored or the drum is out of round, it is necessary to replace the drum or regrind it, or to turn it down in a lathe until the drum is again smooth and true. Care must be taken that the drums do not become too thin, as pressure exerted by the brake band or brakeshoe may distort them or cause a severe squeak.

287. Brakeshoes

a. Brakeshoes are made of malleable iron, cast steel, drop-forged steel, pressed steel, or cast aluminum. Pressed steel is generally used because it is cheaper to produce in large quantities. Steel shoes expand at about the same rate as the drum when heat is generated by brake application, thereby maintaining the clearance between the brake drum and brakeshoe under most conditions.

b. A friction lining riveted or bonded to the face of the shoe makes contact with the inner surface of the brakedrum. Semitubular brass rivets are used because brass does not unduly score the drums when the lining is worn. Aluminum rivets are not very satisfactory because they are corroded very readily by salt water.

c. The bonded lining is not riveted, but is bonded directly to the shoe with a special cement. After application, the shoe is baked at a predetermined temperature to insure proper setting of the cement.

d. It is not always necessary to rivet the lining to the shoes. In some brakes, the lining is not fastened to either the shoes or the drum, but floats between them and is held in place by a lining retainer on one side and the brake shield on the other.

288. Lining

Variation in brake design and different conditions of operation make it necessary to have various types of brake lining. Woven or molded brake linings are used in automotive vehicles. Molded brake lining (fig. 495) is made of dense, hard, compact materials, and is cut into blocks to fit different sizes of brakeshoes. Its frictional qualities are low because it has a smooth surface, but it dissipates heat rapidly and wears longer than the woven type. Woven brake lining (fig. 496) is made of asbestos fiber, cotton fiber, and copper or bronze wire. After being woven, the lining is treated with compounds intended to lessen the effects of oil and water if they should come in contact with it. However, oil in particular will reduce the frictional quality of the lining even after treatment. The lining is also compressed and heat treated before being installed. The main advantage of a woven lining is its high

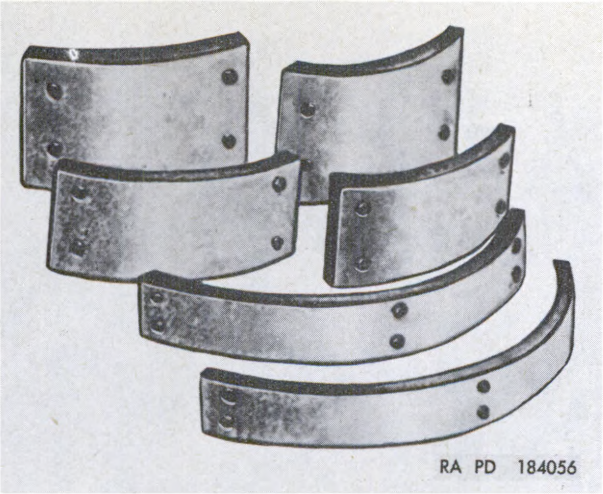


Figure 495. Molded brake lining.

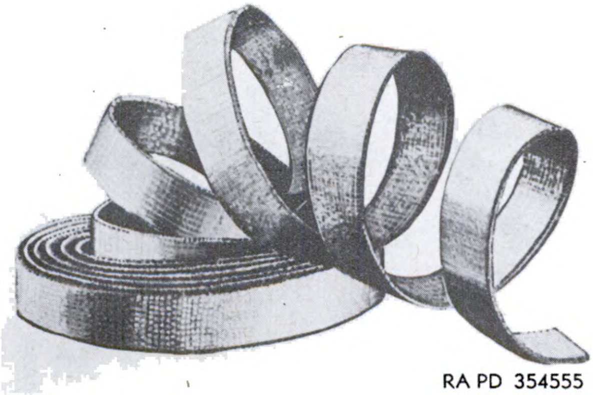


Figure 496. Woven brake lining.

frictional qualities. It does not dissipate heat as rapidly as molded brake lining.

289. Auxiliary Brake Mechanisms

a. General. The auxiliary brake mechanism is a separate mechanical hook-up applied to the transmission or transfer. This arrangement provides a separate means for braking the vehicle if trouble occurs in the service brakes. The two types of transmission brakes in common use are contracting and disk.

b. Contracting.

(1) A typical contracting transmission brake is shown in figure 497. The drum is splined or bolted on the transmission or transfer main shaft. The brake must be designed for either forward or backward motion of the vehicle. For this reason, the brake band is anchored at a point just opposite that at which the operating force is applied. The halves of the brake band then wrap against the drum, preventing rotation in either direction.

(2) The mechanism for operating this brake is usually a simple bellcrank arrangement controlled by the hand lever. A spring disengages the brake band lining when the actuating force is released. Various other mechanisms are employed for operating contracting transmission brakes.

c. Disk. The disk transmission brake (figs. 498 and 499) is generally mounted on the rear of the transmission or transfer case, or on a cross member of the frame. It is designed to dissipate the heat generated in braking. The rotating member of the brake consists of a specially designed steel disk splined or bolted to the transmission main shaft. This disk has two faces which act as the rotating braking surface. Between them are air passages so arranged that a large volume of air passes through them to cool the braking surface when the disk is rotating. One brake shoe covers one-fourth of each disk face. The shoes are supported on swinging brackets and are clamped against the disk faces by means of a cam lever arrangement. A spring removes the shoes from the disk faces when the hand or foot lever is released.

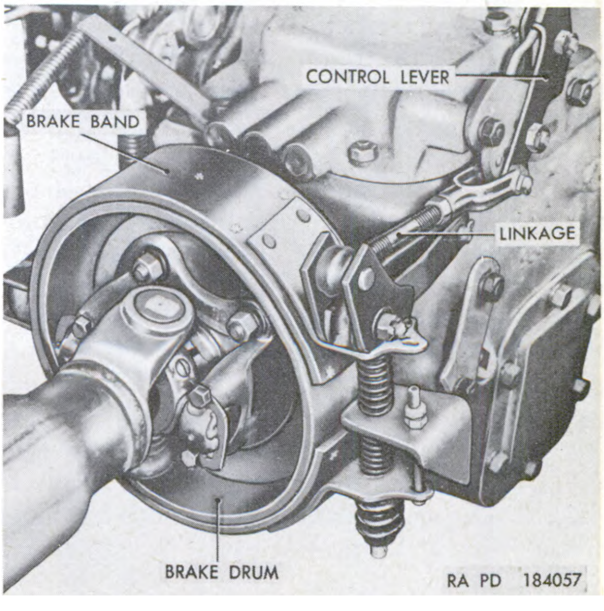


Figure 497. Contracting transmission or propeller shaft brake.

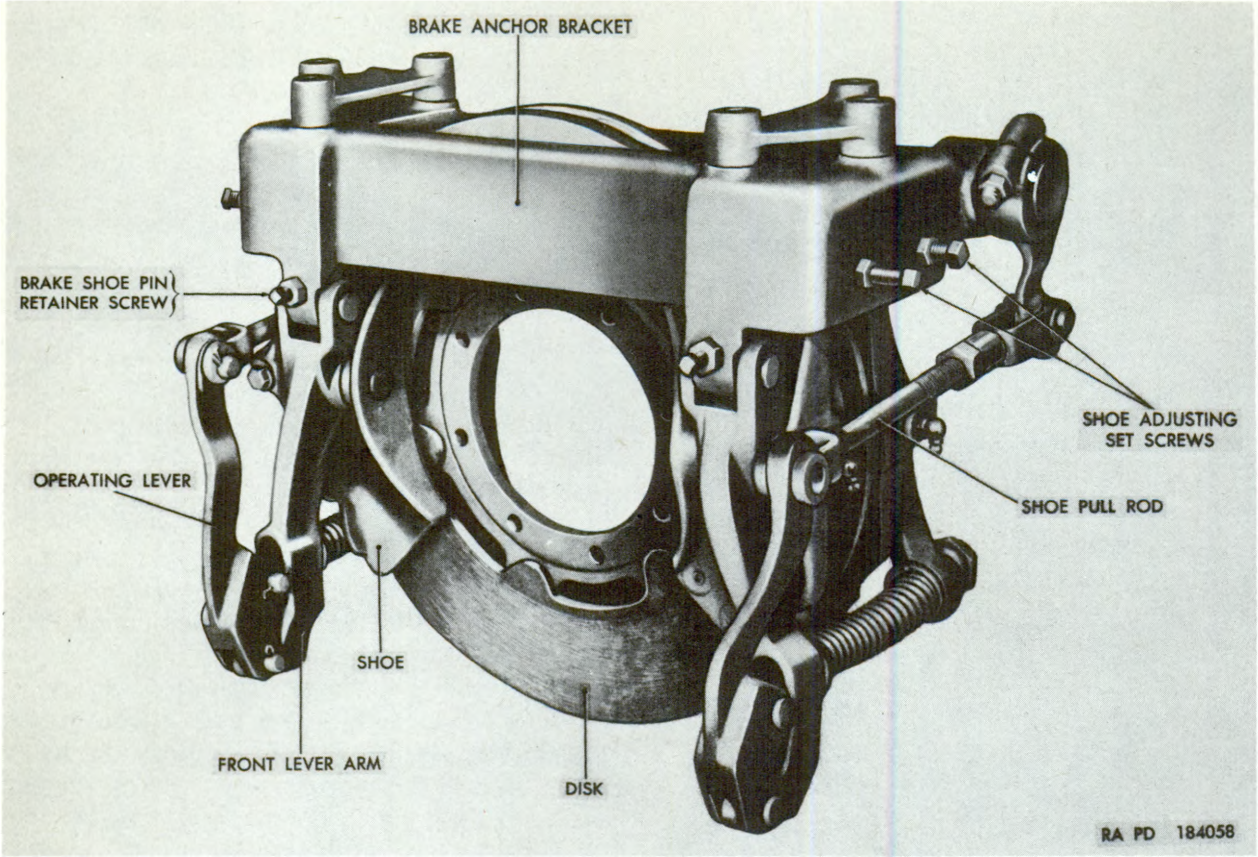


Figure 498. Disk transmission brake—front view.

d. Parking Brake. The parking brake is operated by a hand lever in the driver's compartment, and is used to keep the vehicle stationary when no driver is present. It may act on the wheels, but usually acts on the transmission or transfer and is located immediately behind the transmission or transfer assembly.

e. Advantages and Disadvantages of Transmission Brakes. Transmission and transfer assembly brakes are theoretically more efficient than wheel brakes, since the braking effort is multiplied by the final-drive ratio, and their braking action is perfectly equalized through the differential. Practically, however, they cannot be made as powerful as wheel brakes. They put a severe strain on the power transmission system, and they are not positive in action for they do not prevent differential action from taking place in the drive axle. Under some conditions, the vehicle can move while the brake is applied.

290. Wheel Brake

a. The wheel, or service brakes used for retarding and stopping modern motor vehicles operate on all four wheels. Early models of motor vehicles had wheel brakes on the two rear wheels only, but this practice is obsolete. Four-wheel brakes give increased braking effect and also make possible a much smoother, more even braking action, thereby reducing the tendency to skid. Wheel, or service brakes are interconnected so that they may be adjusted to operate together from one control.

b. Mounting of rotating and nonrotating units of the brake on the wheel is shown in figure 500. The brake drum is mounted directly onto the wheel and provides the rotating braking surface. The brake shield, sometimes called the *backing plate* or *dust shield*, is mounted on some fixed structure such as the axle housing, and forms a support for the nonrotating braking surface and its operating mechanism.

c. The brakeshoes (fig. 501) may be anchored to the brake shield by separate pins or by the same pin. Conical springs usually are used to keep the shoes in position close to the brake shield. A fairly strong retracting spring is hooked between

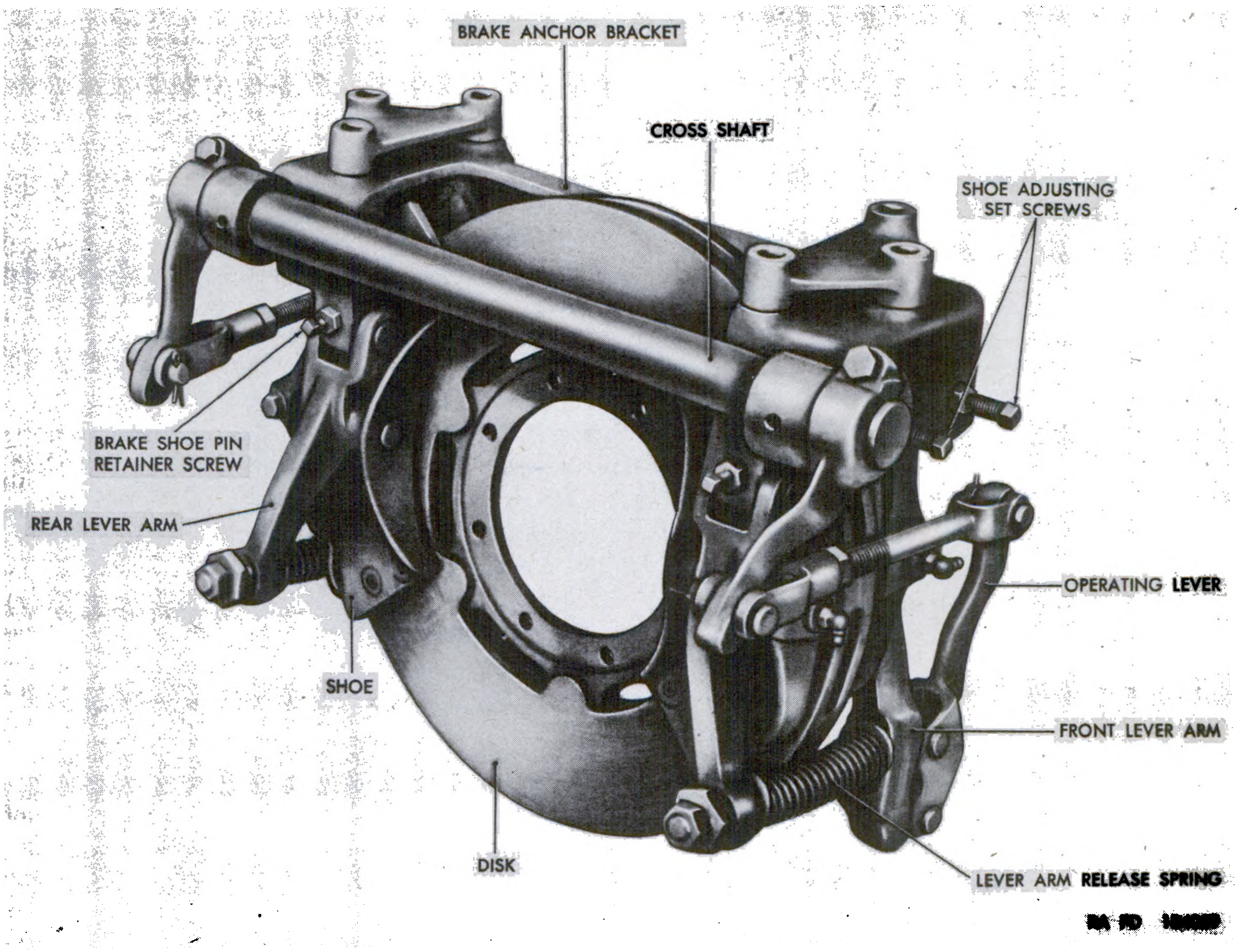


Figure 499. Disk transmission brake—rear view.

the shoes to pull them away from the drum when the brakes are released. With a mechanical hookup, pressure can be applied to the brakeshoes by means of a cam, toggle, or double-lever arrangement. A cam (fig. 493) turned by a small lever is the method most frequently used. Turning the cam by the lever tends to spread the brakeshoes and push them outward against the drum. The material of the wearing surfaces against which the cam bears must be able to withstand considerable pressure and abrasion, since lubrication at this point is difficult and some road grit is certain to find its way into the brake drum. With a hydraulic system, pressure is applied to the brakeshoes by means of a cylinder and piston.

291. Disk Brake

a. General. The disk brake on some models of passenger cars uses a pair of disks, or pressure plates, that are forced against the inner faces of the brake housing for braking action.

b. Construction. The disk brake assembly consists of a pair of pressure plates, or flat rings (fig. 502), faced on one side with brake lining and assembled in a brake housing attached to the wheel (fig. 503). Six steel balls, in series arrangement, are positioned in ramps between the two plates so that, when one plate is turned a few degrees, the balls ride up on the ramps and move the plates away from each other. This outward movement forces the plates into contact with the inner faces of the brake housing for braking action.

c. Operation. When the brakes are applied, a hydraulic wheel brake cylinder (fig. 504), which is attached to the inner pressure plate, operates to force the two plates to rotate, with respect to each other, a few degrees. Actually, there are two of these wheel brake cylinders. Each contains a piston, as shown. When the brakes are applied, the

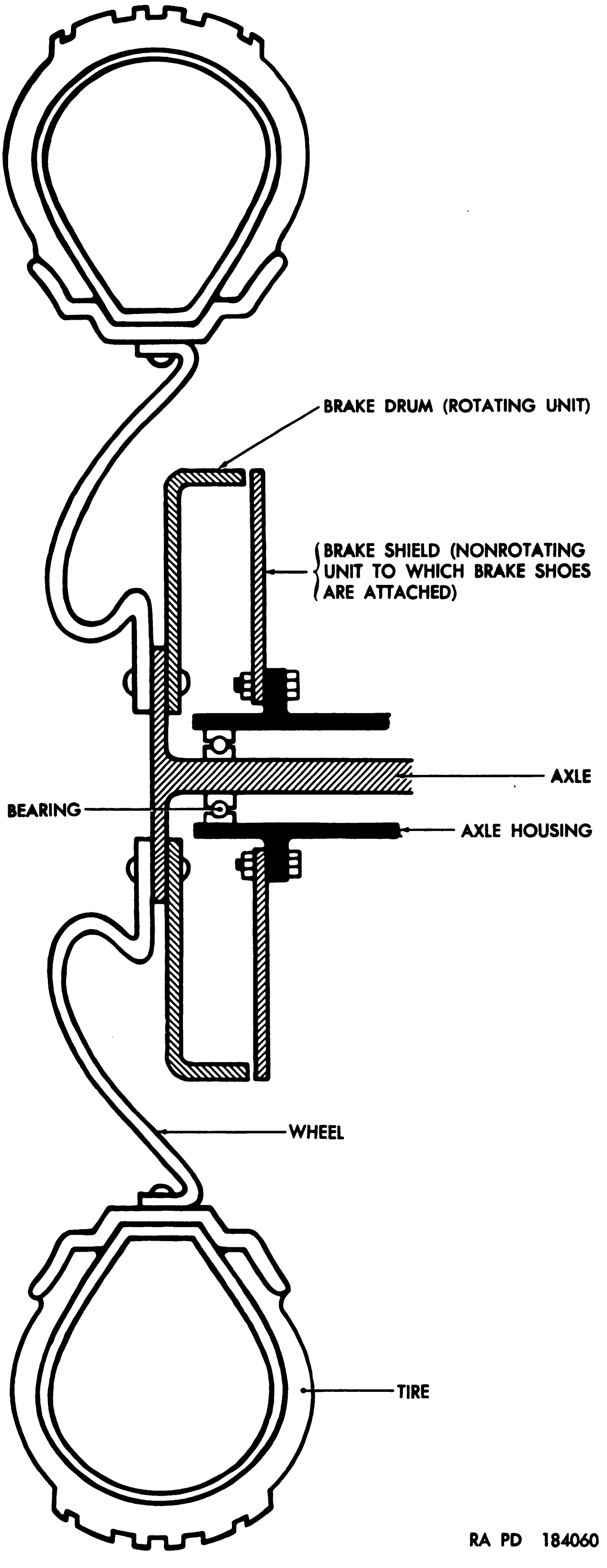

BRAKE DRUM (ROTATING UNIT)
BRAKE SHIELD (NONROTATING UNIT TO WHICH BRAKE SHOES ARE ATTACHED)
AXLE
BEARING
AXLE HOUSING
WHEEL
TIRE
RA PD 184060

Figure 500. Wheel brake mounting.

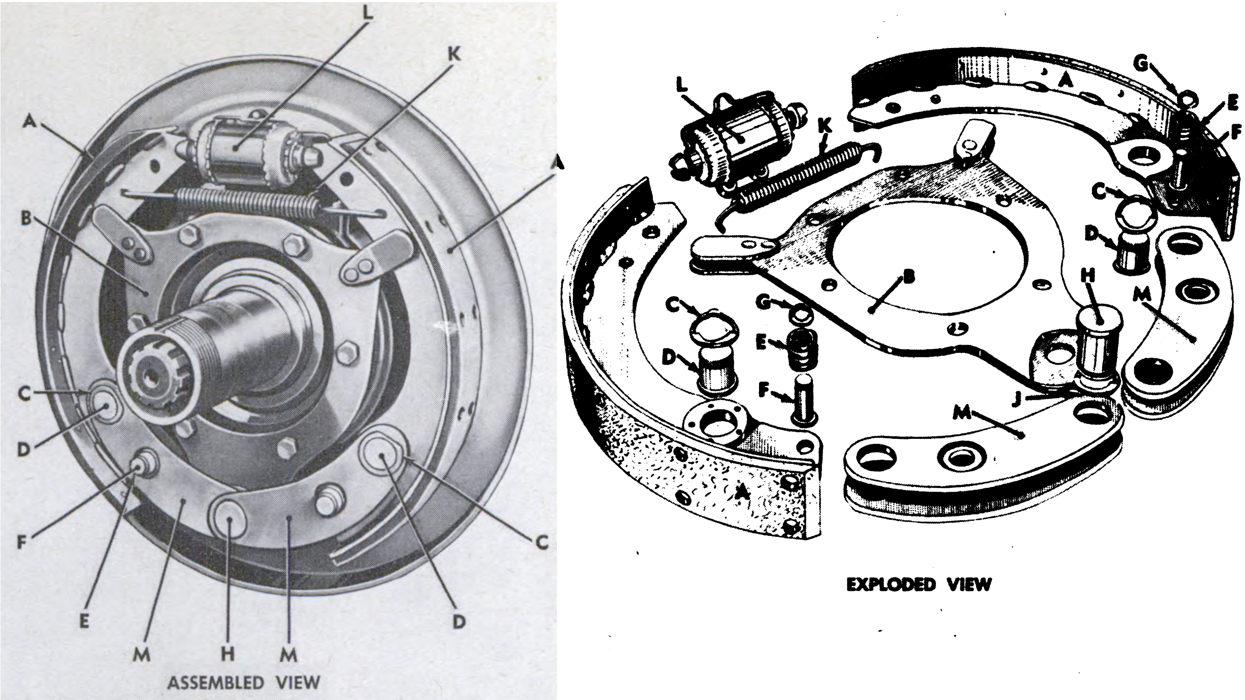
piston is forced outward, thereby pushing through the push rod on the outer plate. This causes the two plates to rotate, and the balls ride up on the ramps and cause the plates to move apart from each other. As they do so, they are forced into tight contact with the inner faces of the rotating wheel brake housing (fig. 505). The braking action then takes place between the inner faces of the brake housing and the brake linings on the pressure plates. The action is partially self-energizing, since the outer plate (in forward motion) tends to rotate further as it comes into contact with the inner face of the wheel brake housing. The frictional contact between the two tends to carry the outer plate on around, and this provides added braking action.

d. A somewhat more complicated disk brake used in the cross-drive transmission (par. 208 *f*) is illustrated in figure 346. In this brake, a series of brake disks, splined alternately to the brake anchor and to the rotating member, are forced together for braking action.

292. Self-Energizing Action

a. The brake-operating linkage alone does not provide sufficient mechanical advantage for positive braking. Some means of supplementing the physical application of the braking system has to be used to increase pressure on the brake shoes. A self-energizing action is very helpful in accomplishing this, once setting of the shoes is started by physical effort. While there are variations of this action, it is always obtained by the shoes themselves, which tend to revolve with the revolving drum.

b. When the brake shoe is anchored (fig. 506), and the drum revolves in the direction shown, the shoe will tend to revolve with the drum when it is forced against the drum. As a result, the shoe will exert considerable pressure against the anchor pin. Since the pin is fixed to the brake shield, this pressure will tend to wedge the shoe tightly in between the pin and the drum as shown. As the initial braking pressure is increased on the cam, the wedging action increases and the shoe is forced still more tightly against the drum to increase the friction. This self-energizing results in more braking action than could be obtained with the actuating pressure alone. Brakes making use of this principle to increase pressures on the braking surfaces are known as *self-energizing* (*or servo*) *brakes.*



ASSEMBLED VIEW

EXPLODED VIEW

A—BRAKE SHOE AND LINING
B—BRAKE SHOE ANCHOR PLATE ASSEMBLY
C—BRAKE SHOE LINK PIN LOCK
D—BRAKE SHOE LINK PIN
E—PIN SPRING
F—PIN
G—PIN LOCK
H—ANCHOR PIN
J—ANCHOR PIN LOCK
K—BRAKE SHOE RETURN SPRING
L—BRAKE SHOE WHEEL CYLINDER
M—BRAKE SHOE LINK

RA PD 184061

Figure 501. Articulating link wheel brake.

c. It is most important that the operator control the total braking action at all times; therefore, the self-energizing action should increase only upon application of additional actuating pressure at the brake pedal. The amount of self-energizing action available depends mainly on location of the anchor pin. As the pin is moved toward the center of the drum, wedging action increases until a point is reached where the shoe will automatically lock. The pin must be located outside this point so that the operator can control the braking.

d. When two shoes are anchored on the bottom of the brake shield (fig. 493), self-energizing action is effective on only one shoe. The other shoe tends to revolve away from its pivot, which reduces its braking action. When the wheel is revolving in the opposite direction, the self-energizing action is produced on the opposite shoe.

e. Two shoes are usually mounted so that self-energizing action is effective on both. This is accomplished by pivoting the shoes to each other and leaving the pivot free of the brake shield. The only physical effort required is for operating the first, or primary, shoe. Both shoes then apply additional pressure to the braking surfaces with no increase in the pressure on the operating linkage. The anchor pins are fitted into slots in the free ends of the brake shoes. This method of anchoring allows the movement of the shoes necessary to expand against the drum when the shoes are forced against the drum, and the self-energizing action of the primary shoe is transmitted through the pivot to the secondary shoe (fig. 507). Both shoes will tend to revolve with the drum and will be wedged against the drum by the one anchor pin. The other anchor pin will cause a similar action when the wheel is revolving in the opposite direction.

f. Another type of brakeshoe mounting (fig. 501) consists of two links anchored together on the brake shield with the end of each link pivoted to one of the brakeshoes. This articulated mounting allows more even application of the braking surfaces because of the freedom of movement of the brakeshoes. Each shoe is self-energizing in opposite directions.

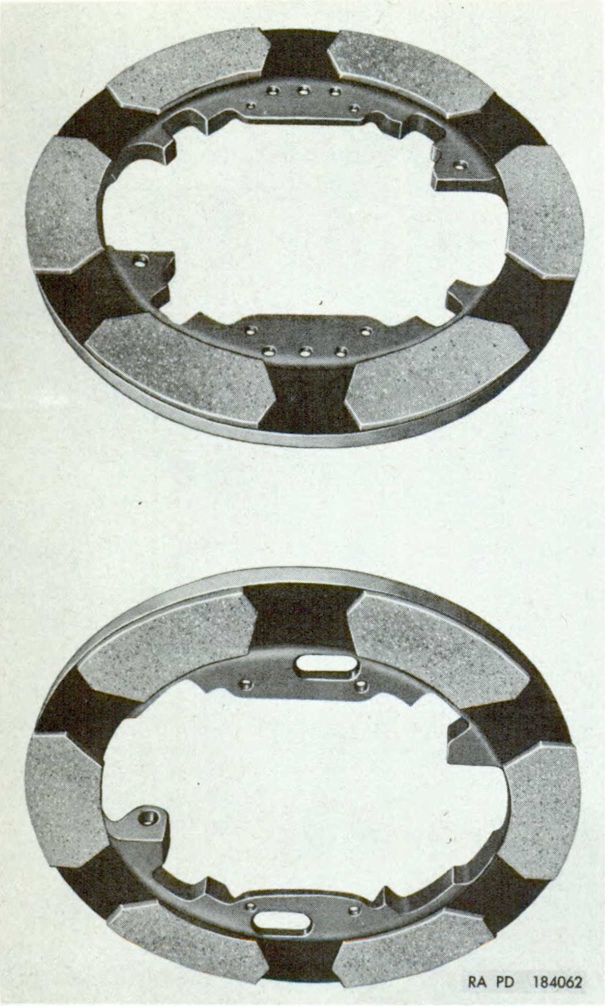

RA PD 184062

Figure 502. Brake lining segments on the pressure plates.

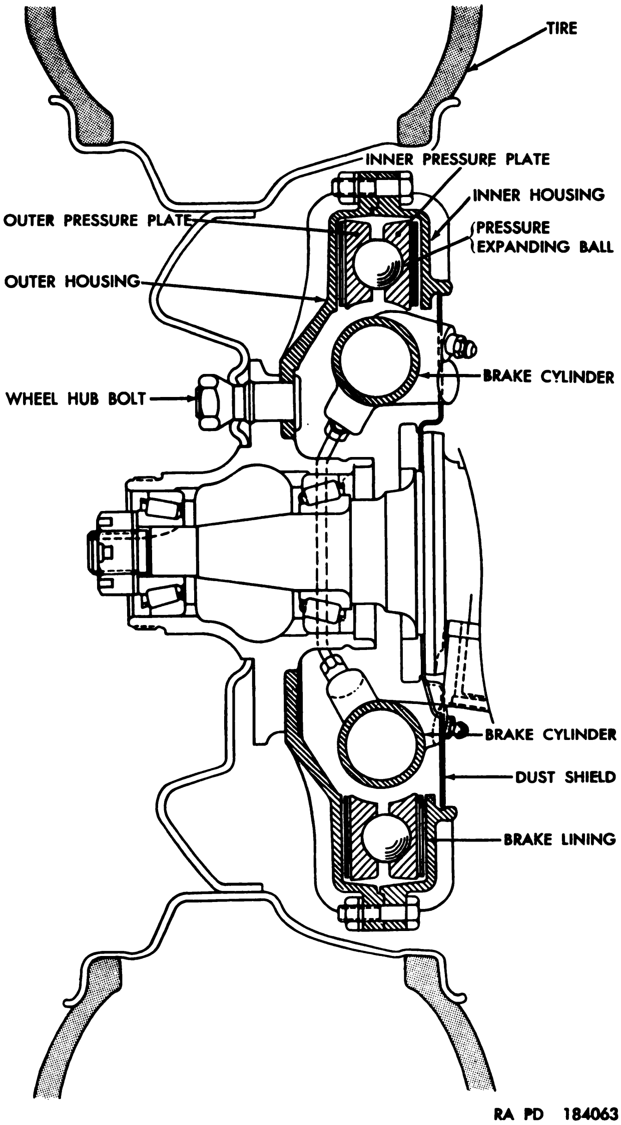
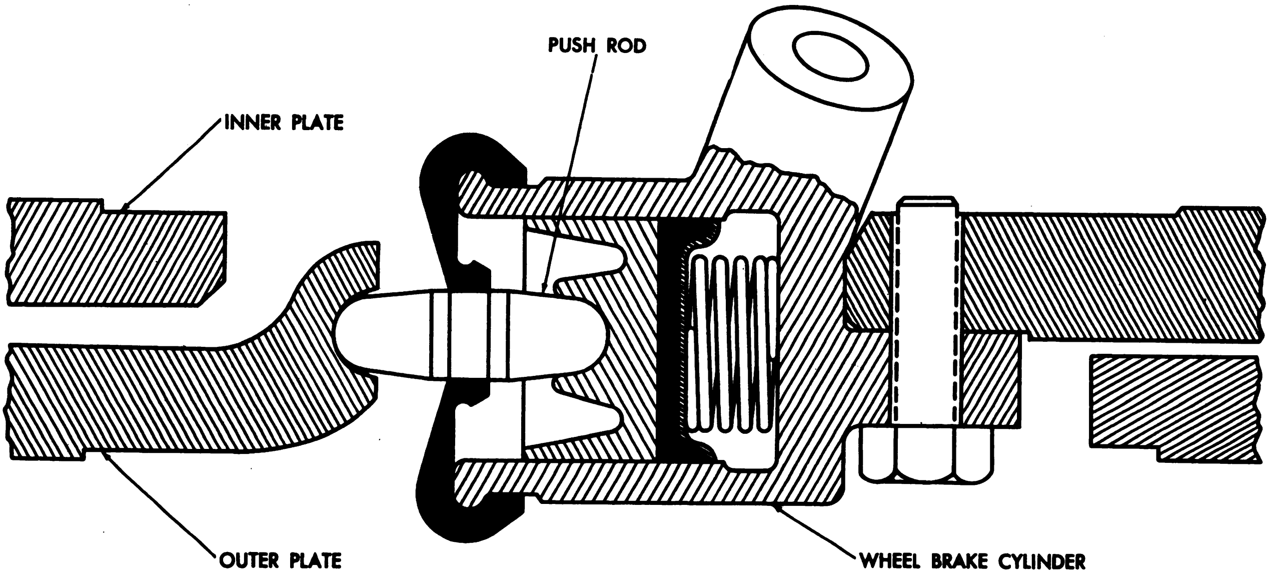
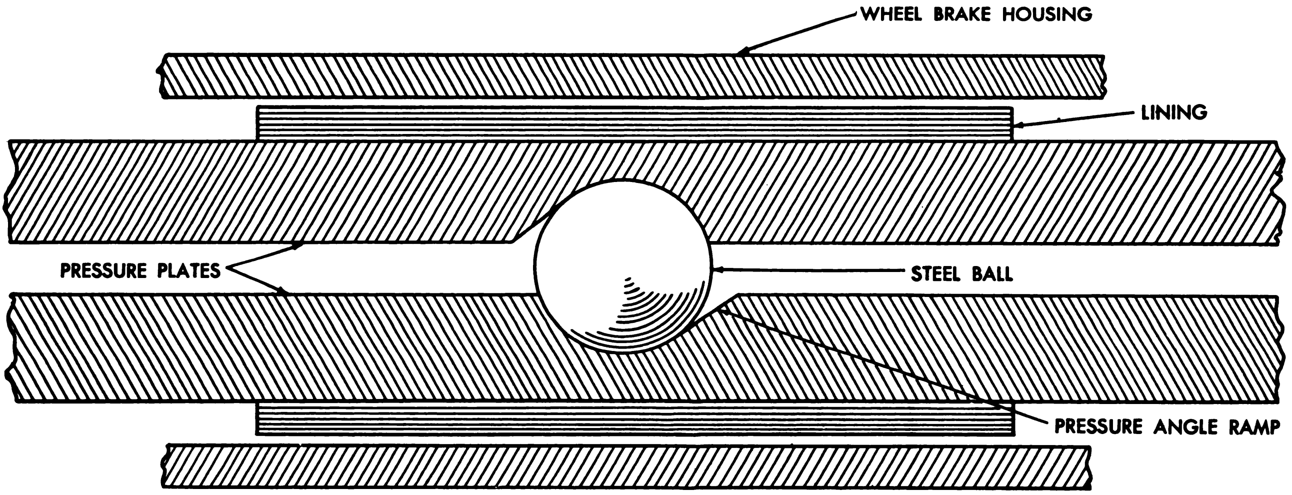

TIRE
INNER PRESSURE PLATE
INNER HOUSING
OUTER PRESSURE PLATE
PRESSURE
EXPANDING BALL
OUTER HOUSING
BRAKE CYLINDER
WHEEL HUB BOLT
BRAKE CYLINDER
DUST SHIELD
BRAKE LINING
RA PD 184063

Figure 503. Disk brake—sectional view.

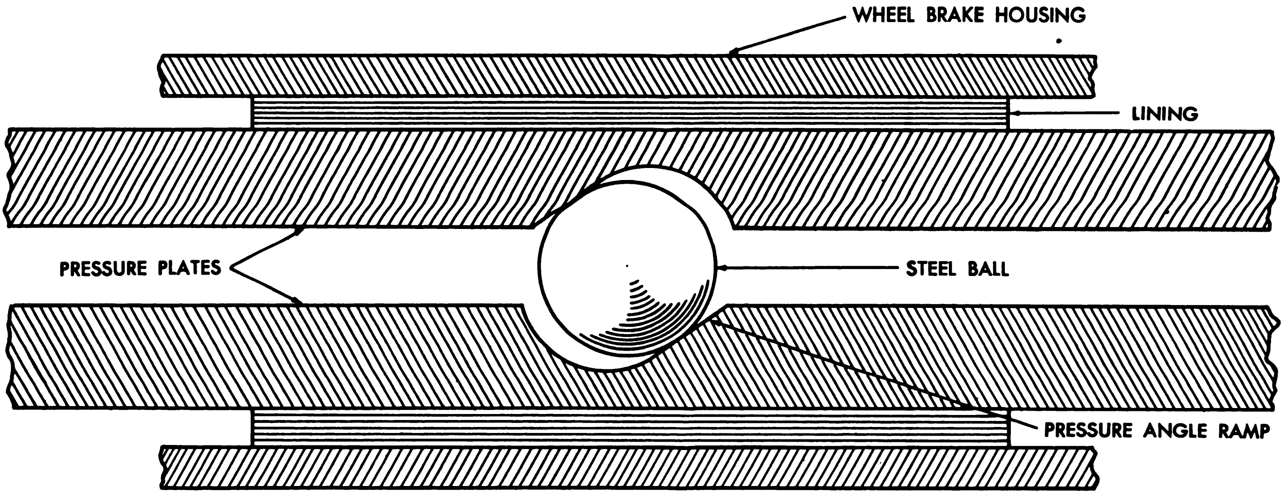

PUSH ROD
INNER PLATE
OUTER PLATE
WHEEL BRAKE CYLINDER

RA PD 184064

Figure 504. Hydraulic wheel brake cylinder—sectional view.


WHEEL BRAKE HOUSING
LINING
PRESSURE PLATES
STEEL BALL
PRESSURE ANGLE RAMP

NO BRAKING ACTION—PRESSURE PLATES REMAIN STATIONARY


WHEEL BRAKE HOUSING
LINING
PRESSURE PLATES
STEEL BALL
PRESSURE ANGLE RAMP

BRAKING ACTION—PRESSURE PLATES FORCED FURTHER APART

RA PD 184065

Figure 505. Showing braking action of disk brakes.

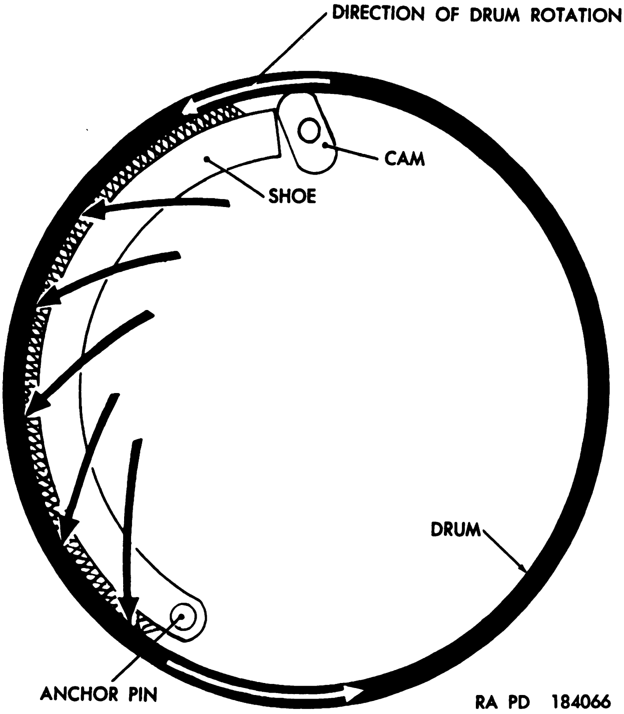


Figure 506. Brakeshoe self-energizing action.

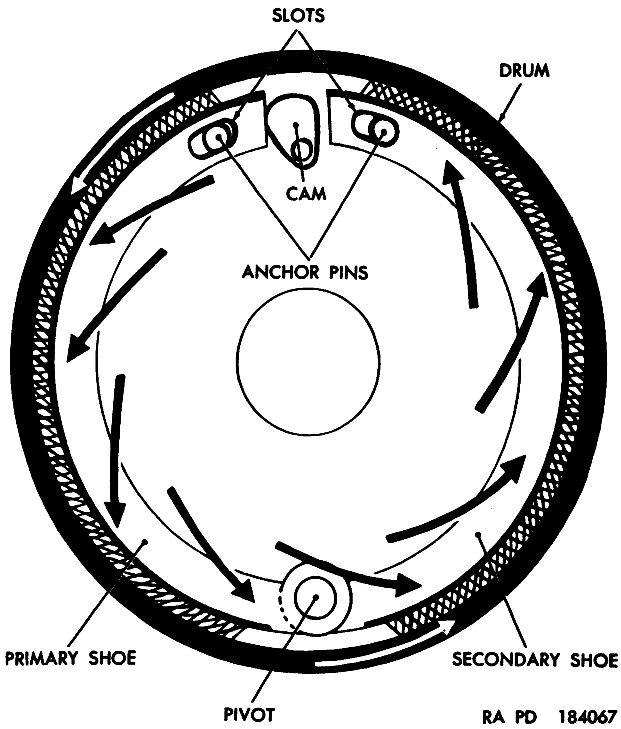


Figure 507. Mounting for two self-energizing brakeshoes.

Section III. MECHANICAL SYSTEM

293. Means of Actuation

a. The energy supplied by the operator's foot in pushing down on the brake pedal is transferred to the brake mechanism on the wheels by various means. A mechanical hookup has been used since the earliest motor vehicles, but hydraulic pressure is most extensively used at the present time. Mechanically operated braking systems are practically obsolete. However, mechanical hookups are used for a portion of the braking systems in many vehicles.

b. Power-operated brakes have come into widespread use on heavy-duty vehicles. The power medium acts as a booster to assist the operator in applying the brakes. Air, vacuum, and electric systems are employed to obtain power operation of the brakes. These systems are discussed in paragraphs 303 through 308.

294. Hookup

a. Cross Shaft.

(1) In a mechanical braking system the force applied to the pedal is transmitted to the brakes by means of rods and cables. The mechanical linkage may be arranged in various ways, but its operation is essentially the same. In order to have all the wheel brakes applied uniformly, a cross shaft is provided near the center of the vehicle frame on which are mounted the levers connected to the rods and cables leading to the wheel brakes. The brake pedal is also connected to a lever on the cross shaft (fig. 508).

(2) When the pedal is depressed, the cross shaft (fig. 508) is turned so that the levers on the top of the shaft are turned backward and those on the bottom of the shaft forward. By connecting the front brake rods to the levers on the top of the shaft and the rear brake rods to the levers on the bottom of the shaft, all the brake rods are pulled together and the four wheel brakes are applied at the same time.

(3) The usual practice in mechanical systems has been to link the handbrake to the footbrake so that both operate the same braking units. With such an arrangement, the handbrake linkage incorporates an overrunning slot in the handbrake pull rod where it is connected to a lever on the cross shaft. This allows the

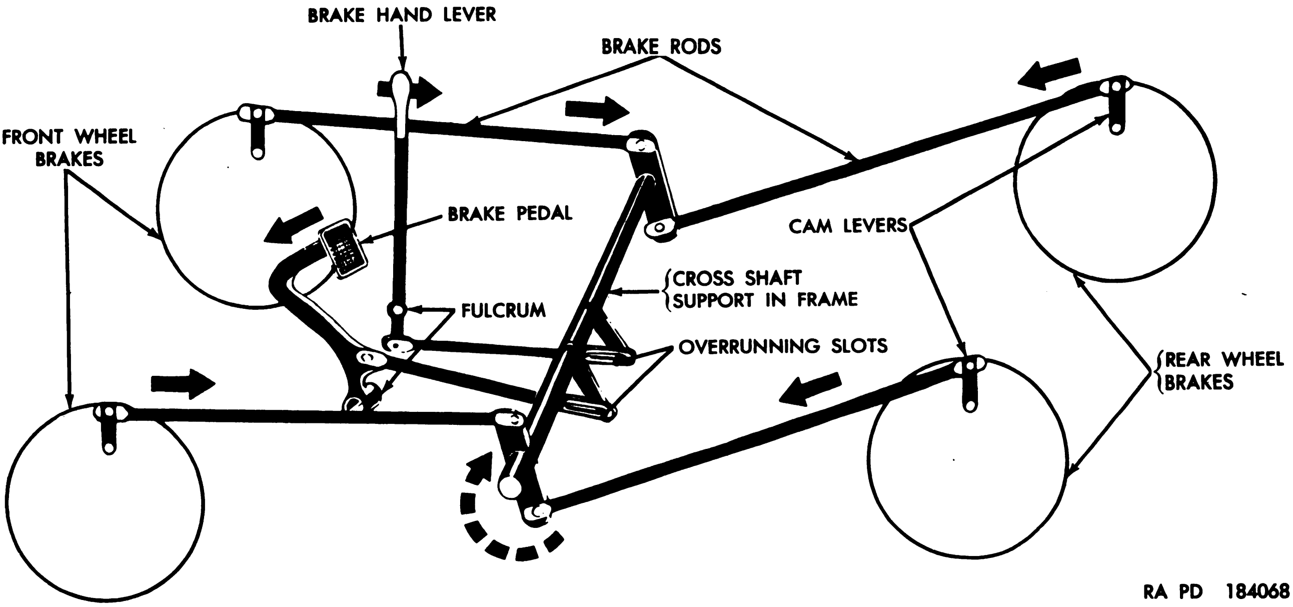

BRAKE HAND LEVER
BRAKE RODS
FRONT WHEEL BRAKES
BRAKE PEDAL
CAM LEVERS
CROSS SHAFT SUPPORT IN FRAME
FULCRUM
OVERRUNNING SLOTS
REAR WHEEL BRAKES
RA PD 184068

Figure 508. Mechanical brake system with single cross shaft.

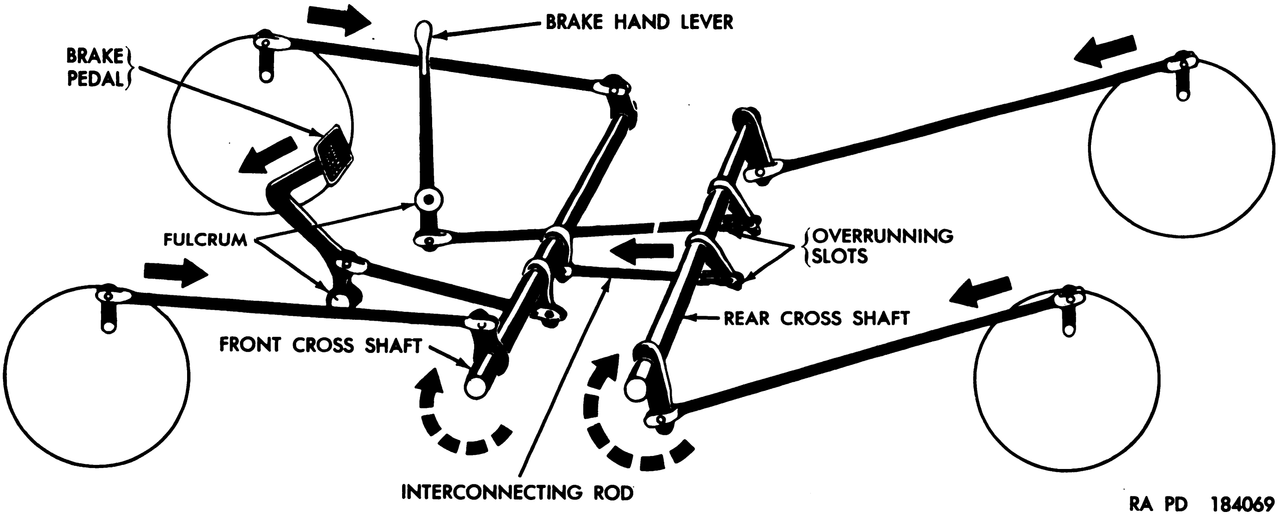

BRAKE HAND LEVER
BRAKE PEDAL
FULCRUM
OVERRUNNING SLOTS
REAR CROSS SHAFT
FRONT CROSS SHAFT
INTERCONNECTING ROD
RA PD 184069

Figure 509. Mechanical brake system with two cross shafts.

pedal linkage to operate without interference from the hand lever. Both controls may be independently operated by also incorporating an overrunning slot in the footbrake linkage.

b. Two Cross Shafts. In some mechanical brake arrangements, two cross shafts (fig. 509), are provided, so that the handbrake is applied to the shoes on the rear wheels only. The front and rear cross shafts are connected together by an interconnecting rod joined to a lever on each shaft. An overrunning slot must be provided on the interconnecting rod (fig. 509) and the handbrake pull rod, if the rear wheel brakes only are to be applied by the brake hand lever. Some braking systems incorporate additional shoes on the rear wheels for the handbrake, in which case the handbrake has its own cross shaft and hookup, and is in no way connected with the foot, or service, brakes.

295. Front Wheel Control

The hookup of the brake rods to the front wheels must be designed to allow the wheels to turn without locking in any position. If the front wheels lock, steering is destroyed. One means of con-

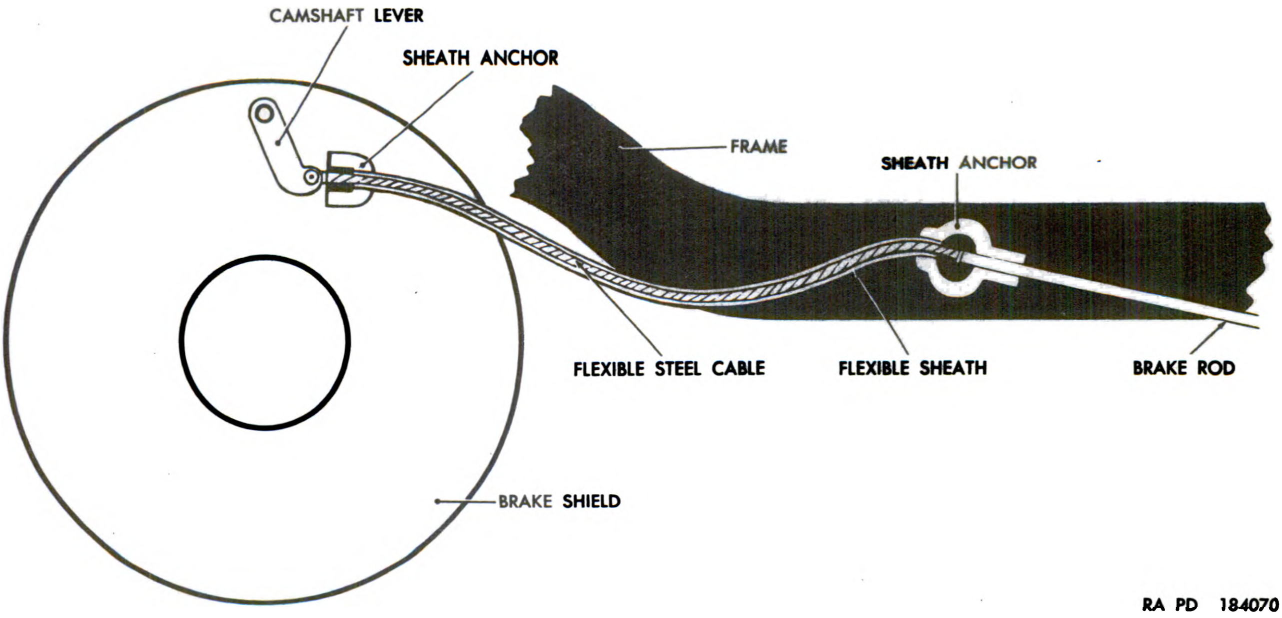


Figure 510. Brake-operating steel cable.

trolling the front wheels is the use of the brake rod attached to a camshaft, with a small universal joint above the steering knuckle pivot. A more popular and satisfactory method employs a flexible steel cable connecting the end of the brake rod to the brake camshaft lever (fig. 510). Because of the flexibility of the cable and its sheath, motion of the wheel does not affect tension on the cable. Flexible steel cables may also be used advantageously on the rear wheels, because of the vibration of the wheels when traveling over the road. On some braking systems, the pressure on the wheel brakes is evenly distributed by various types of equalizers. Equalizers are designed to take up all the slack in the hookup to each brake so that all brakes will be applied at the same time. This prevents the possibility of too much pressure being applied to any one brake, which would lock that wheel and probably make the vehicle skid. One of the main reasons why the mechanical braking system has been supplanted is the difficulty of maintaining equal pressure on all brakes.

Section IV. HYDRAULIC SYSTEM

296. Principles

a. In hydraulic braking systems, the pressure applied at the brake pedal is transmitted to the brake mechanism by a liquid. To understand how pressure is transmitted by a hydraulic braking system, it is necessary to understand the fundamentals and principles of hydraulics. Hydraulics is the study of liquids in motion, or the pressure exerted by liquids conveyed in pipes or conduits.

b. One well-known hydraulic principle is that liquids cannot be compressed under ordinary pressures. This may be demonstrated by placing a weight on top of a piston fitted to a jar (fig. 511). The force of the weight does not change the level of the liquid, hence, it does not diminish the volume or compress the liquid.

c. Another well-known hydraulic principle is that force exerted at any point upon a confined liquid is distributed equally through the liquid in all directions. That is, if a total force of 20 pounds, including piston and weight, is placed upon liquid in a jar, and if the piston in the jar has an area of 5 square inches, the unit hydraulic pressure is increased by 20/5, or 4 psi. This is illustrated in figure 512. A gage inserted at any point in the jar will indicate the same pressure of 4 psi, since the liquid transmits the pressure equally throughout the jar.

d. Use of these hydraulic principles may be illustrated by interconnecting two jars of the same diameter containing liquid (fig. 513). If a force is exerted on a piston in one jar (the left jar in fig. 513), a piston placed in the other jar will

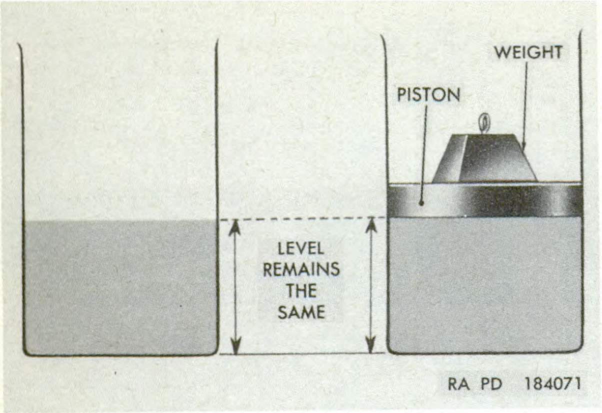

WEIGHT
PISTON
LEVEL REMAINS THE SAME
RA PD 184071

Figure 511. Noncompressibility of liquids.

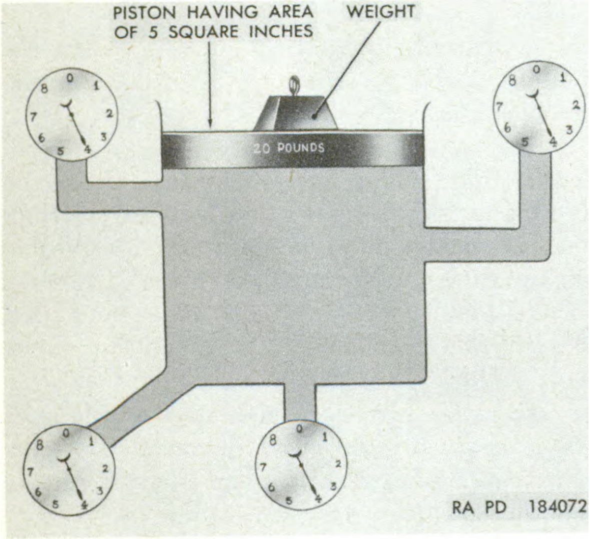

PISTON HAVING AREA OF 5 SQUARE INCHES
WEIGHT
20 POUNDS
RA PD 184072

Figure 512. Equal distribution of force upon confined liquid.

receive the same amount of force, due to the transmission of pressure by the liquid. When the areas of the two pistons are equal, moving one piston produces identical movement in the other piston because the liquid is not compressible and therefore maintains the same volume.

e. By connecting one jar with another jar which has twice the diameter and therefore four times the area of the first jar (fig. 514), the results are somewhat different, although the same basic facts apply. When a force is exerted on the piston in the small jar, the piston in the large jar will receive four times as much force because the hydraulic pressure acts on four times the area. Since the liquid will always occupy the same volume, the large piston will move one-fourth as far as the small piston. Thus, a mechanical advantage is obtained very similar to that obtained from a simple lever.

f. With four jars, all of the same diameter, connected to a central jar (fig. 515), an approximation of the action in 4-wheel brakes is obtained. A force exerted on the piston in the central jar will be transmitted to each of the other jars so that the piston in each will receive an identical force but will move only one-fourth as far as the central piston.

g. If the four jars have a larger diameter than the central jar, the total pressure on each of the four pistons is greater than that applied to the central one, and each of the four pistons moves less than one-fourth as far as the central piston. Hydraulic brake systems operate in such a manner.

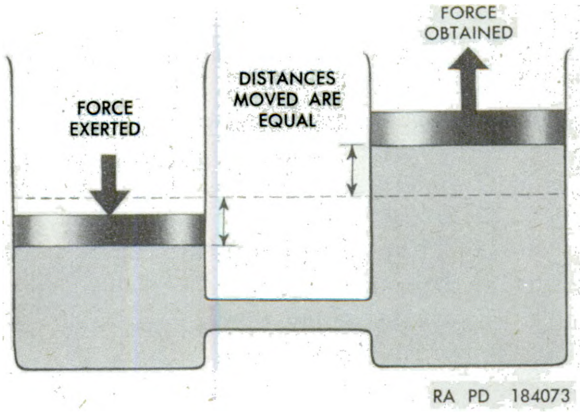

FORCE OBTAINED
DISTANCES MOVED ARE EQUAL
FORCE EXERTED
RA PD 184073

Figure 513. Distribution of forces in hydraulic system using same size pistons.

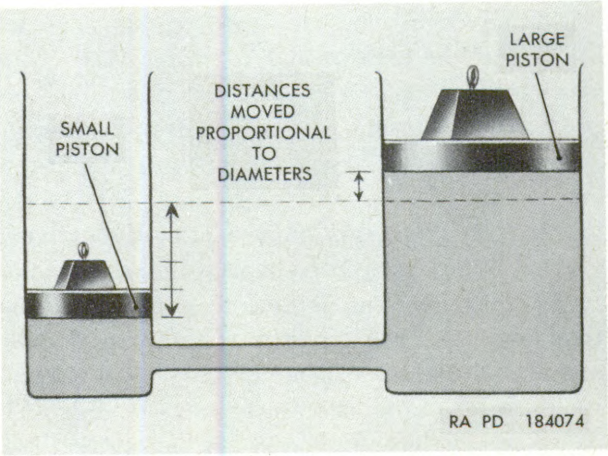

LARGE PISTON
DISTANCES MOVED PROPORTIONAL TO DIAMETERS
SMALL PISTON
RA PD 184074

Figure 514. Distribution of forces in hydraulic system using different size pistons.

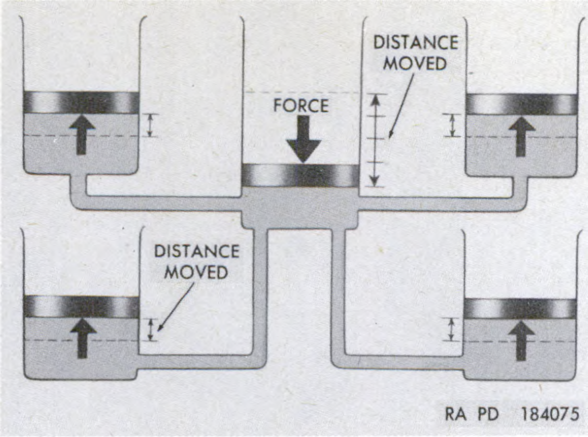


Figure 515. Four jars connected to a central jar.

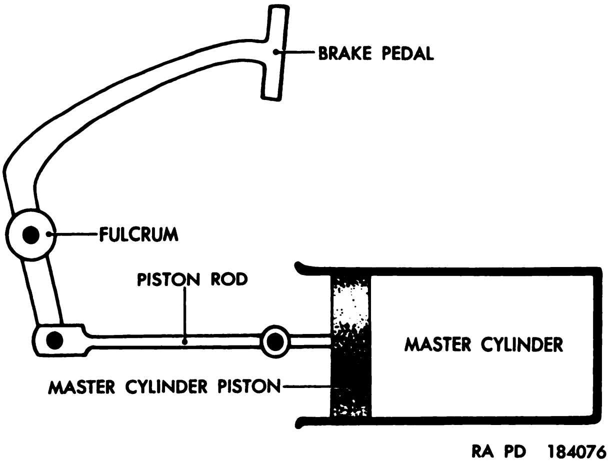


Figure 516. Foot pedal linkage to piston in master cylinder.

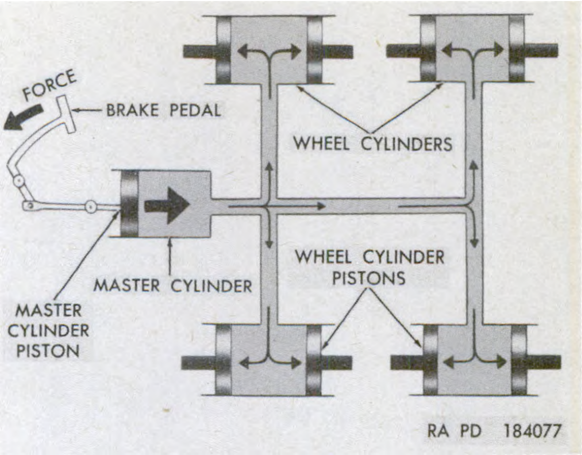


Figure 517. Diagram of hydraulic brake system.

297. Operation

a. In a hydraulic brake system, the force is applied to a piston in a master cylinder that corresponds to the central jar (fig. 515). The brake pedal operates the piston by a linkage (fig. 516). Each wheel brake is provided with a cylinder fitted with opposed pistons connected to the brake shoes.

b. The brake pedal, when depressed, moves the piston within the master cylinder, forcing the brake liquid or fluid from the master cylinder through tubing and flexible hose into the four wheel cylinders. A diagram of a hydraulic brake system is shown in figure 517.

c. The brake fluid enters each of the wheel cylinders between opposed pistons, making the pistons move the brakeshoes outward against the brakedrum. As pressure on the pedal is increased, greater hydraulic pressure is built up within the wheel cylinders and, consequently, greater force is exerted against the ends of the shoes.

d. When pressure on the pedal is released, retracting springs on the brakeshoes return the wheel cylinder pistons to their release position, forcing the brake fluid back through the flexible hose and tubing to the master cylinder.

298. Master Cylinder

(fig. 518)

a. General. The master cylinder housing is an iron casting incorporating a large reservoir for the brake fluid. The cylinder is sometimes a unit by itself, in which case a supply tank is provided to feed the fluid to the master cylinder by gravity. The reservoir carries sufficient reserve fluid to insure proper operation of the braking system. It is filled through a hole at the top which is well sealed by a removable filler cap containing a vent. The cylinder is connected to the reservoir by two drilled ports, a large intake-port and a small bypass port.

b. Piston. The piston is a long, spool-like member with a rubber secondary cup seal at the outer end and a rubber primary cup which acts against the brake liquid just ahead of the inner end. This primary cup is kept against the end of the piston by a return spring. A steel stop disk, held in the outer end of the cylinder by a retainer spring, acts as a piston stop. A rubber boot covers the piston end of the master cylinder to prevent dust and other foreign matter from entering it. This boot is vented to prevent air from being compressed within it.

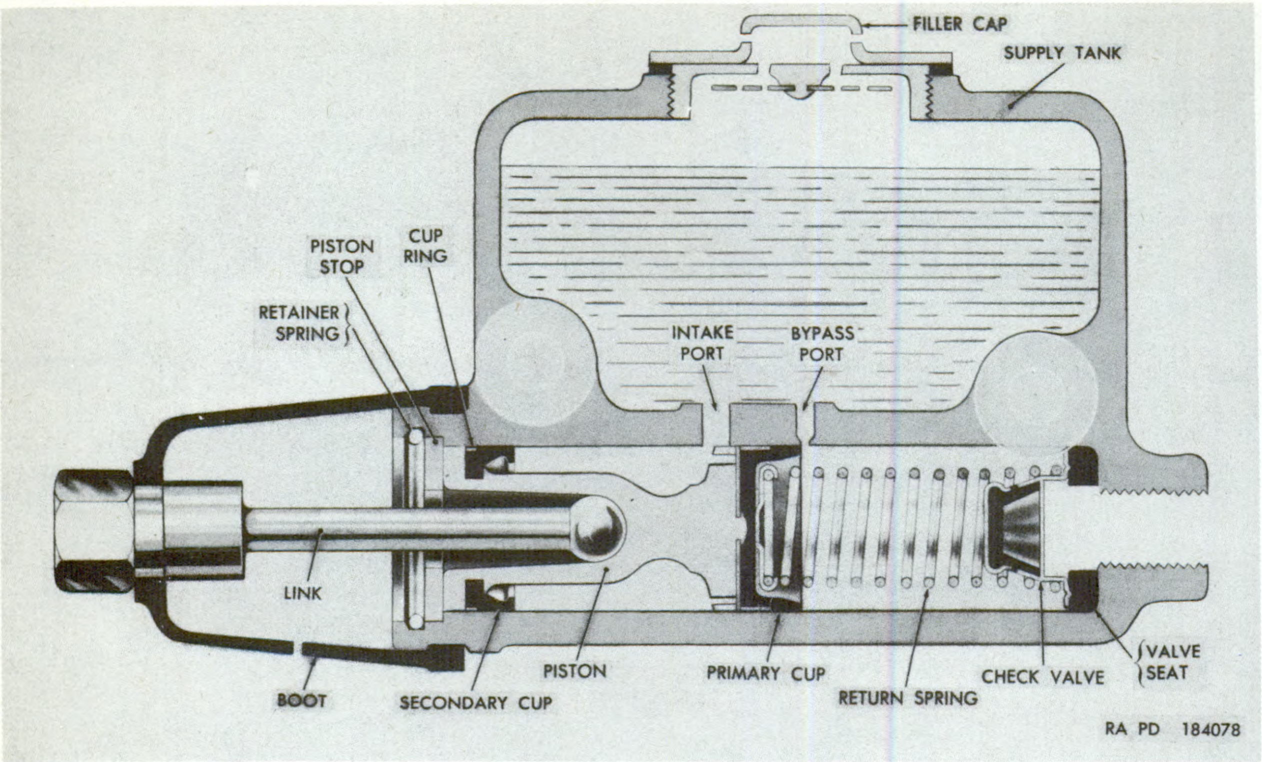

FILLER CAP
SUPPLY TANK
PISTON STOP
CUP RING
RETAINER SPRING
INTAKE PORT
BYPASS PORT
LINK
BOOT
SECONDARY CUP
PISTON
PRIMARY CUP
RETURN SPRING
CHECK VALVE
VALVE SEAT
RA PD 184078

Figure 518. Master hydraulic brake cylinder—cross sectional view.

c. Check Valve. In the head of the master cylinder is a combination inlet and outlet check valve (fig. 518) held in place by the piston return spring. The check valve consists of a rubber valve cup incased in a steel valve case which seats on a rubber valve seat that fits in the end of the cylinder. In some designs, the check valve consists of a spring-operated outlet valve seated on a valve cage, rather than a rubber-cup outlet valve. The principle of operation is the same. The piston return spring normally holds the valve cage against the rubber valve seat to seal the brake fluid in the brake line.

299. Wheel Cylinder

a. General. The wheel cylinder (fig. 519) changes hydraulic pressure to the mechanical force that actually pushes the brakeshoes against the drums. The wheel cylinder housing is a casting mounted on the brake backing plate. Inside the cylinder are two pistons which are moved in opposite directions by hydraulic pressure and which, at the same time, push the shoes against the drum. The pistons or piston stems are connected directly to the shoes. Rubber piston cups fit tightly in the cylinder bore against each piston to prevent the escape of brake liquid. There is a light spring between the cups to keep them in position against the pistons. The open ends of the cylinder are fitted with rubber boots to keep out foreign matter. Brake fluid enters the cylinder from the brake line connection between the pistons. At the top of the cylinder, between the pistons, is a bleeder hole through which air is

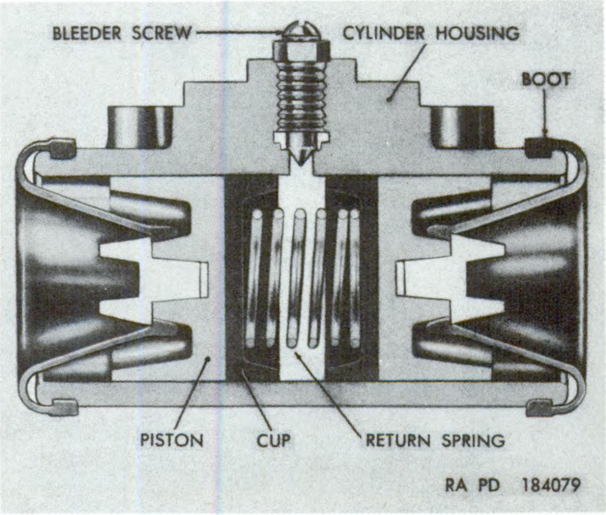

BLEEDER SCREW
CYLINDER HOUSING
BOOT
PISTON
CUP
RETURN SPRING
RA PD 184079

Figure 519. Wheel cylinder—cross sectional view.

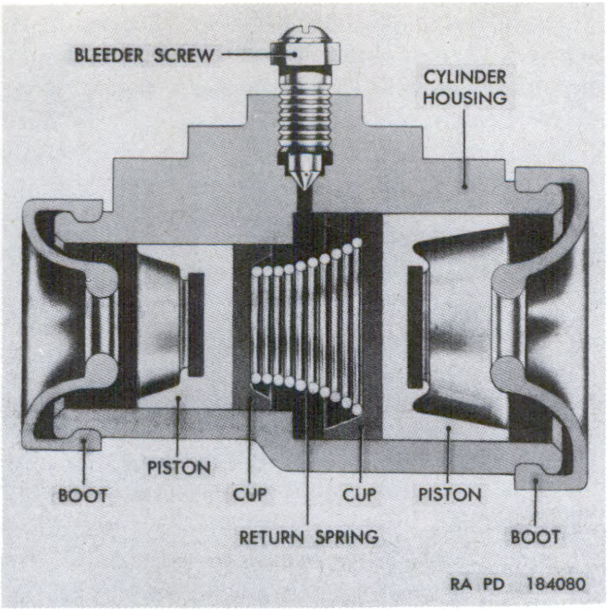


Figure 520. Stepped wheel cylinder—cross sectional view.

released when the system is filled with brake fluid.

b. Variation in Arrangement. A stepped wheel cylinder (fig. 520) is used to compensate for faster rate of wear on the front shoe than on the rear shoe, due to self-energizing action. By using a larger piston for the rear shoe, the shoe receives more pressure to offset the self-energizing action on the front shoe. This requires a stepped wheel cylinder with two bore sizes. If it is desired that both shoes be independently self-energizing, especially on front wheels, it is necessary to have two wheel cylinders, one for each shoe. Each cylinder has a single piston, and is mounted on the opposite side of the brake backing plate from the other cylinder. Such an arrangement is shown in figure 521.

300. Hill Holder

The hill holder provides greater ease of vehicular control on hills and in traffic. The device is connected to the clutch pedal and keeps the brakes applied as long as the clutch pedal is depressed when the car is on an upgrade, even after the brake pedal is released. The driver is then able to use his right foot for the accelerator pedal.

301. Handbrake and Dual Brake System

a. The handbrake in vehicles with a hydraulic system operates mechanically either on the transmission or transfer, or on the brakeshoes of the rear wheels. The transmission or transfer brake, entirely independent of the hydraulic system, is of the type described in paragraph 289. When the handbrake operates on the wheels, it is usually linked to the same shoes that are operated by the hydraulic pistons. Toggle leverage (fig. 522) is used to apply the shoes. With this arrangement, the shoes are applied either hydraulically by the brake pedal, or mechanically by the hand lever.

b. In addition to the hydraulic system, some cars are fitted with a mechanical device designed to act on rear wheel brakes after the brake pedal has traveled a predetermined distance toward the toeboard. In normal operation, the braking action is entirely one of hydraulic force, the mechanical hookup working in connection with the hydraulic system. With the correct quantity of fluid in the lines and brakes properly set, the mechanical hookup is inactive; however, if the hydraulic system fails, the mechanical linkage acts as a safeguard. This mechanical hookup serves a further use as it may be connected to the hand brake lever for parking.

302. Brake Fluid

The liquid used for hydraulic braking is termed *brake fluid.* It is composed chiefly of equal parts

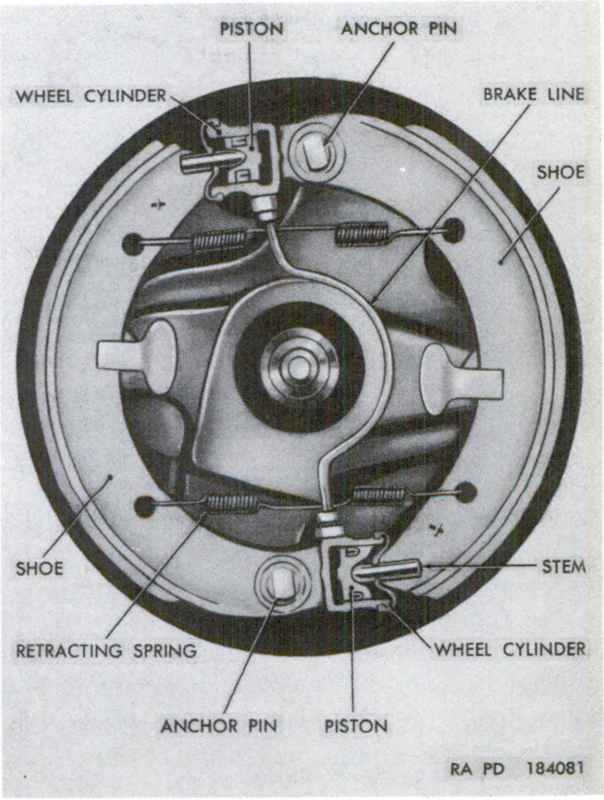


Figure 521. Single-piston two-cylinder mounting.

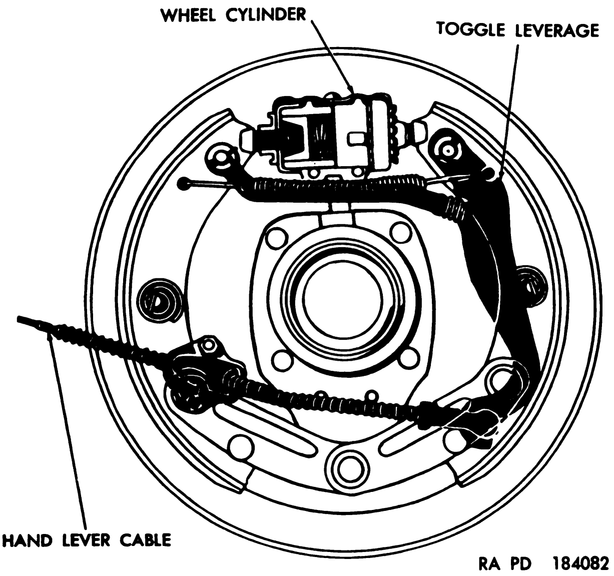


Figure 522. Handbrake linkage on hydraulically operated brake.

of alcohol and castor oil. This combination forms a liquid that does not freeze or boil at the temperatures encountered in year-around operation of motor vehicles.

a. Brake Lines. The brake lines which transmit the fluid from the master cylinder to the wheel cylinders are made of tubing and flexible hose. Connections are tight so that no liquid can escape from the system. Tubing and flexible hose must be able to withstand hydraulic pressure developed when the brakes are fully applied.

b. Bleeding. Air will enter the hydraulic brake lines and wheel cylinders if fluid level is too low, if fluid leaks out, or if any part of the system is disconnected. Since air seriously affects braking efficiency, the hydraulic system is usually bled whenever brakes are adjusted. All wheel cylinders must be separately bled to make sure that all air is removed.

Section V. POWER-OPERATED BRAKES

303. General

Heavy motor vehicles and their towed loads require, in general, more powerful braking effect than can be exerted by the unaided efforts of the operator. Three systems have been developed in which the operator simply controls a valve or switch which releases stored energy, as needed, to produce braking action of the desired intensity. The actuating force is produced by compressed air, vacuum, or electricity.

304. Air System

a. General. The fundamental characteristic of this system is that the brakes, although controlled by the driver, are applied by compressed air. Compressed air provides sufficient braking force to control even the heaviest vehicles.

b. Compressed-Air Principle (fig. 523). Unlike liquids, gases are easily compressed. If a gas such as air is confined and a force applied to it, it is compressed and has less volume. Such a force may be exerted by placing a weight on a piston that fits into a container. The air that originally filled the entire container is pressed into only a portion of the container, due to the force of the weight upon it. The pressure of the compressed air, resulting from the force exerted upon it by the weight, will be equally distributed in all directions just as it is in a liquid. Compressed air under pressure may be conveniently stored and made available for the power application of brakes.

c. Essential Action. An air pump or compressor driven by the engine is used to compress air and force it into a reservoir where it is stored under pressure and made available for operating the brakes. Air under pressure in the reservoir is released to the brake lines by an air valve operated by the brake pedal. This released air goes to brake chambers (located close to the wheel brakes) which contain a flexible diaphragm. Against this diaphragm is a plate which is directly connected by linkage to the mechanism on the wheel brakes. The force of the compressed air admitted to the chamber causes the diaphragm to

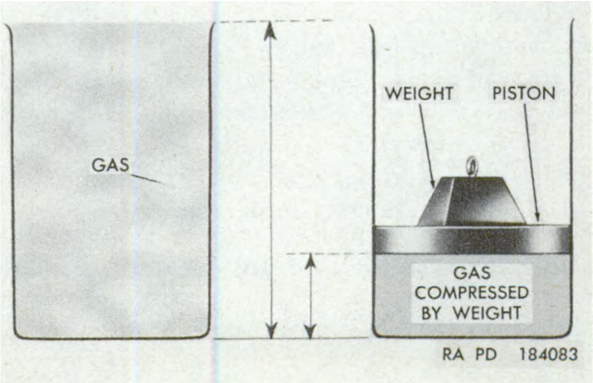


Figure 523. Compressibility of gas.

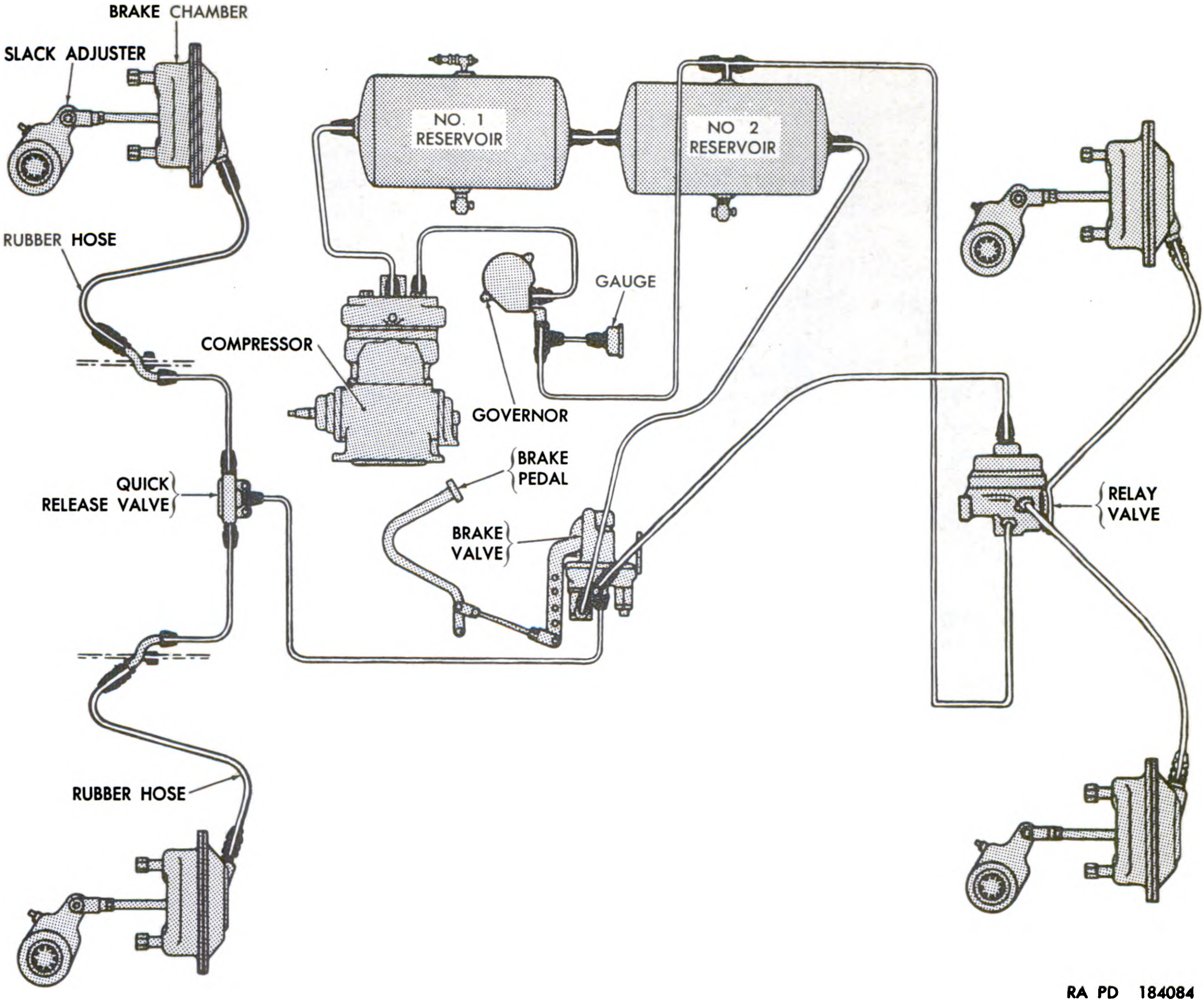

BRAKE CHAMBER
SLACK ADJUSTER
NO. 1 RESERVOIR
NO 2 RESERVOIR
RUBBER HOSE
GAUGE
COMPRESSOR
GOVERNOR
BRAKE PEDAL
QUICK RELEASE VALVE
RELAY VALVE
BRAKE VALVE
RUBBER HOSE
RA PD 184084

Figure 524. Diagram of typical air brake system.

move the plate and operate the brakeshoes through the linkage. Considerable force is available for braking, since operating air pressure may be as high as 100 psi. All brakes on a vehicle, and on a trailer when one is used, are operated together by means of special regulating valves. Operation of trailer brake systems is described in chapter 25.

d. Fundamental Units. A diagram of a typical air brake system used on a motor vehicle is shown in figure 524. The fundamental units and their functions are listed in (1) through (8) below.

(1) Air compressor, driven directly from engine crankshaft or from one of auxiliary shafts, to furnish compressed air for brake operation.

(2) Governor, to limit pressure produced by compressor within a predetermined range.

(3) Reservoir, to receive air from compressor and store it for use in the braking system. Two reservoirs are usually used.

(4) Air brake valve, to control brake operation by directing flow of air from reservoir to brake chambers when brakes are applied, and from brake chambers to atmosphere when brakes are released.

(5) Brake chambers, one for each wheel, to convert pressure of compressed air into mechanical force for applying brakes.

(6) Quick release valve, to speed up exhaust of brake chambers not close to brake

valve so that all the brakes may be quickly released.

(7) Relay valve, used on trailers and trucks with long wheelbases, to speed operation of rear wheel brakes. On trucks with short wheelbases, the shorter length of brake lines permits rapid rear brake action without aid of a relay valve.

(8) Slack adjusters which provide a means of adjusting the brakes to compensate for wear in linings.

305. Air Brake System Components

a. Air Compressor.

(1) *Description.* Air compressors are generally single-acting reciprocating units, either self-lubricated or lubricated from the vehicle engine lubricating system. Both water-cooled and air-cooled cylinder heads are used. Compressors having a displacement of approximately 7 cfm have two cylinders, while those with a displacement of 12 cfm have three cylinders. Typical air compressors are shown in figures 525, 526, and 527.

(2) *Operation.*

(*a*) The air compressors operate continuously while the engine is running, but the actual compression of air is controlled by the governor.

(*b*) With a partial vacuum created on the piston downstroke, intake ports are uncovered near the bottom of the stroke. Intake ports are covered as the piston starts its upstroke. Air in the cylinder is compressed. The pressure developed lifts the discharge valve and the compressed air is discharged to the reservoirs (fig. 524). The discharge valve closes as soon as pressure is relieved when the piston starts its downstroke.

(*c*) When the reservoir air pressure reaches the maximum setting of the governor, air under pressure is allowed by the governor to pass into a cavity below an unloading diaphragm in the cylinder head. This air pressure lifts one end of the unloading lever, which pivots on its pin and forces the unloading valves off their seats. With the unloading valves off their seats, the unloading cavity forms a passage between the cylinders above the pistons. Air thus passes back and forth through the cavity between the cylinders and compression is stopped. Drop in air pressure below the minimum setting of the governor causes it to release the air pressure from beneath the unloading diaphragm, allowing the unloading valves to return to their seats. Compression is then resumed.

b. Governor.

(1) *Description.* The governor maintains the air pressure in the reservoir, between the desired maximum and minimum values, by controlling the compressor unloading mechanism. The Bourdon gage principle of a curved metal tube that tends to straighten under internal pressure is utilized.

(2) *Operation.* Air under pressure from the reservoir is always present below the lower valve and in the tube. As air pressure increases, the load of the tube (fig. 528) on the lower valve is relieved, since the tube tends to straighten. When reservoir air pressure reaches the cutout setting of the governor, the spring tube load on the valves has been reduced sufficiently to permit the air pressure to raise the valves. The upper valve closes the exhaust port and the lower valve opens the connection for the air under pressure to the compressor unloading mechanism. If air pressure drops to the governor cut-in setting, the pressure of the spring tube on the valves increases and forces the valves down, opening the upper valve and seating the lower valve. Air under pressure from the unloading mechanism is allowed to escape through the exhaust port while the air under pressure from the reservoir is sealed off by the lower valve.

c. Air Brake Valve.

(1) *Description.* The air brake valve lever is connected to the brake pedal. Movement of the lever controls the operation of the inlet and exhaust valves (fig. 529) which control the air under pressure delivered to or released from the brake chambers.

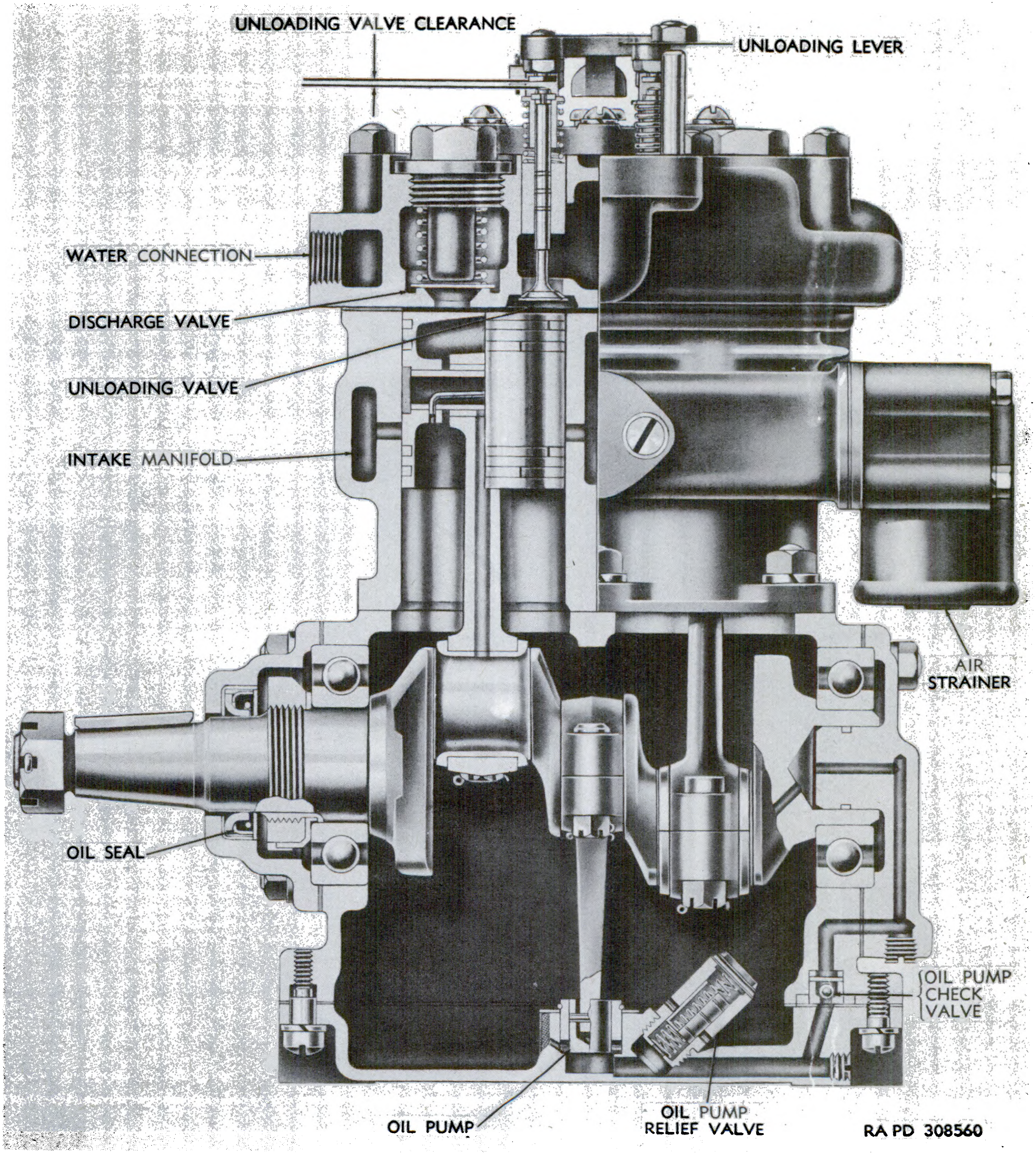

UNLOADING VALVE CLEARANCE
UNLOADING LEVER
WATER CONNECTION
DISCHARGE VALVE
UNLOADING VALVE
INTAKE MANIFOLD
AIR STRAINER
OIL SEAL
OIL PUMP CHECK VALVE
OIL PUMP
OIL PUMP RELIEF VALVE
RA PD 308560

Figure 525. Two-cylinder self-lubricated air compressor—cross sectional view.

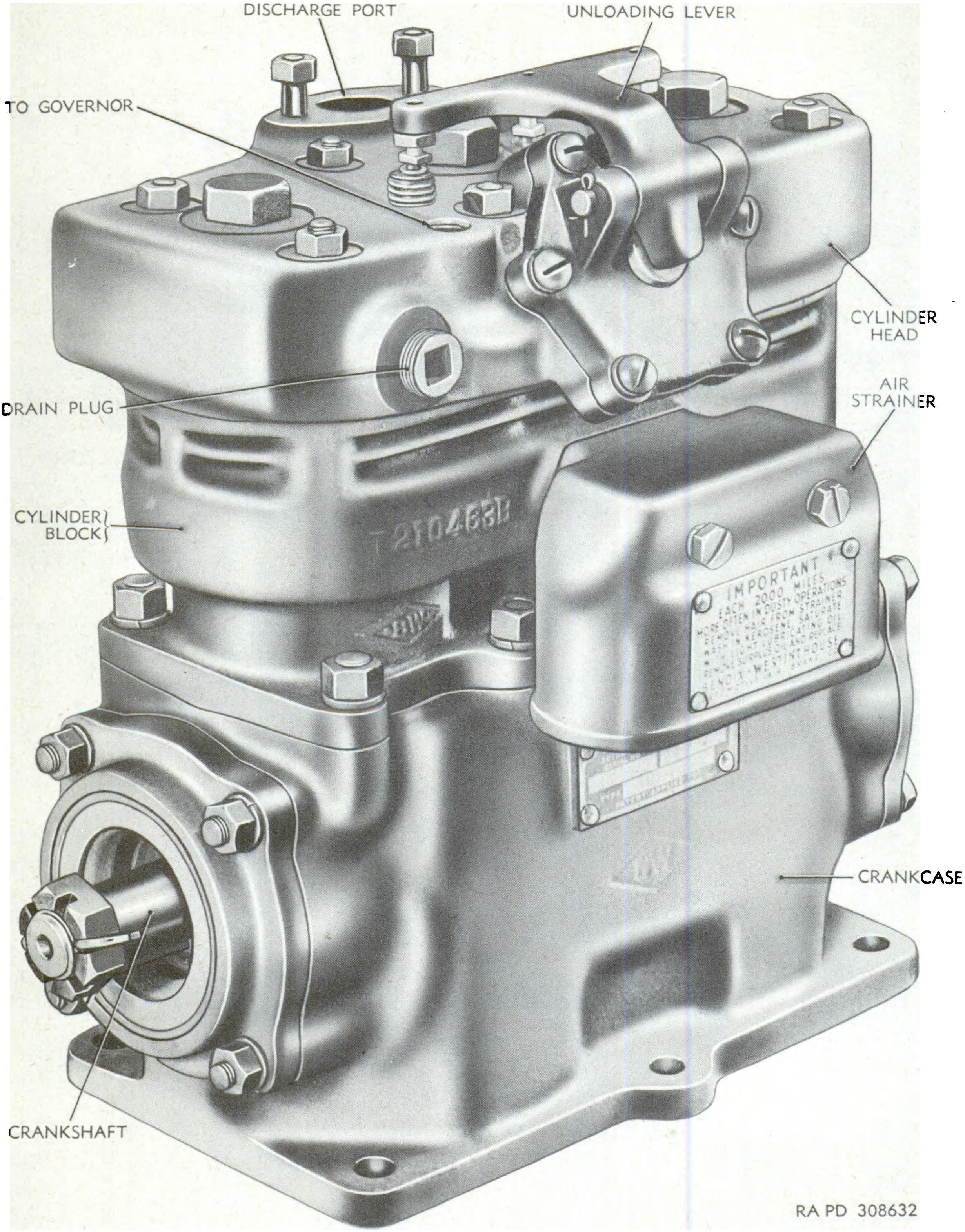
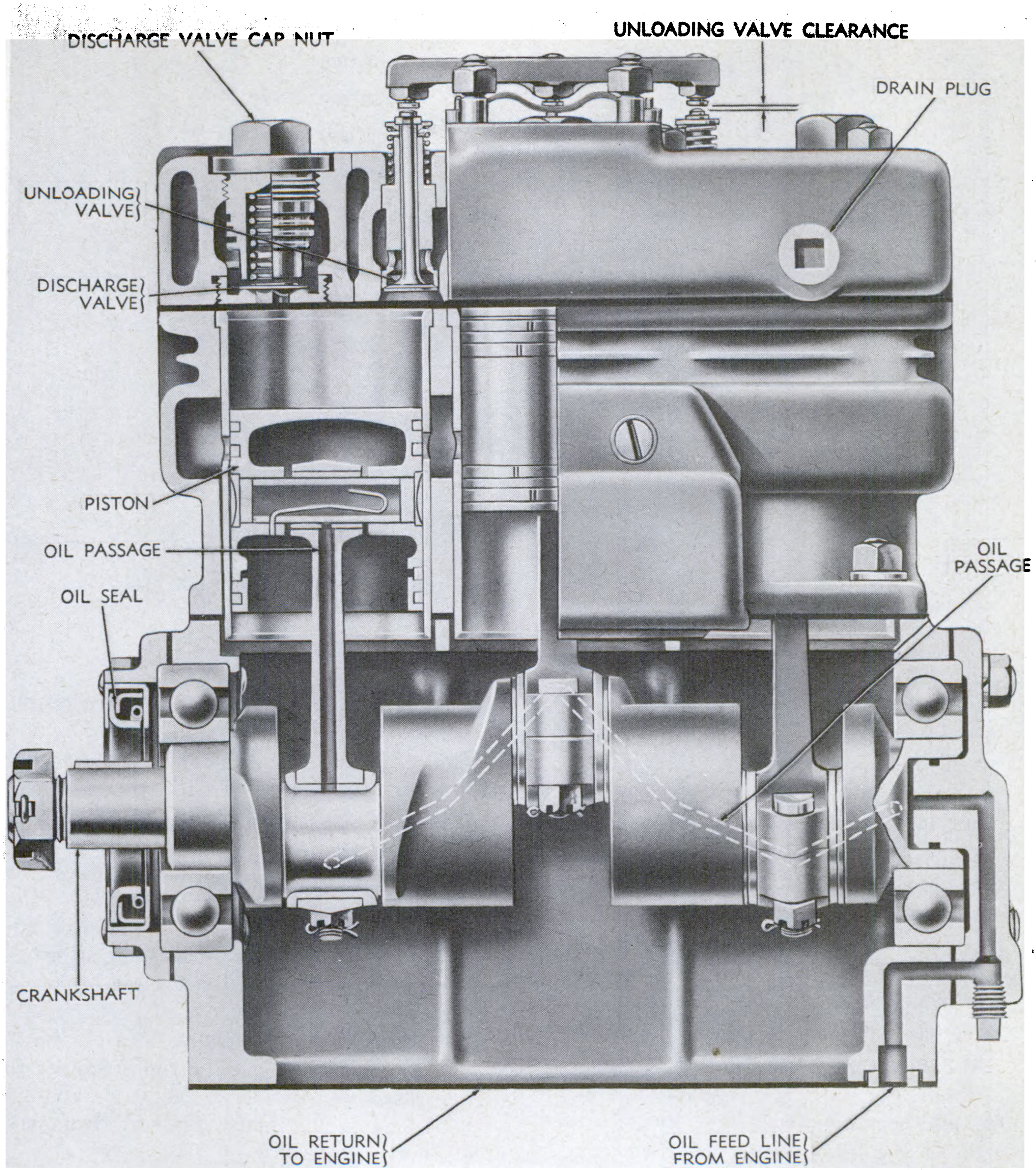

DISCHARGE PORT
UNLOADING LEVER
TO GOVERNOR
CYLINDER HEAD
DRAIN PLUG
AIR STRAINER
CYLINDER BLOCK
IMPORTANT
EACH 2000 MILES
MORE OFTEN IN DUSTY OPERATIONS
REMOVE HAIR FROM STRAINER
WASH IN KEROSENE, SATURATE
BENDIX-WESTINGHOUSE
CRANKCASE
CRANKSHAFT
RA PD 308632

Figure 526. Three-cylinder engine-lubricated air compressor.


DISCHARGE VALVE CAP NUT
UNLOADING VALVE CLEARANCE
DRAIN PLUG
UNLOADING VALVE
DISCHARGE VALVE
PISTON
OIL PASSAGE
OIL SEAL
OIL PASSAGE
CRANKSHAFT
OIL RETURN TO ENGINE
OIL FEED LINE FROM ENGINE

RA PD 308561

Figure 527. Three-cylinder engine-lubricated air compressor—cross sectional view.

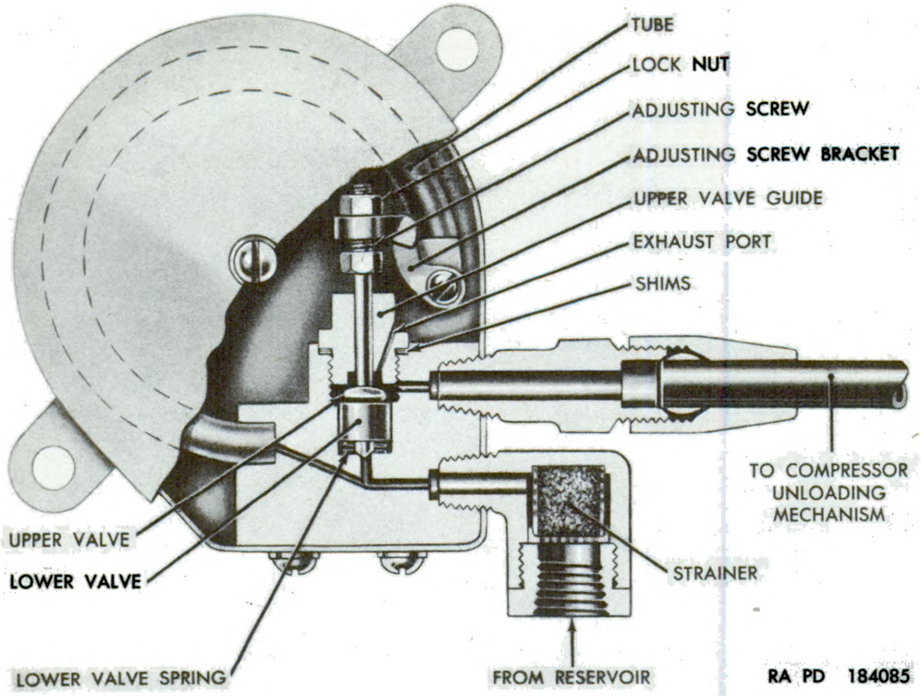


Figure 528. Air brake system governor—cross sectional view.

(2) *Operation.* As the brake pedal is depressed, the brake valve lever moves toward its applied position. The plunger and regulating spring are forced down, applying mechanical force on the diaphragm. The exhaust valve spring is weaker than the intake valve spring, so the exhaust valve is forced downward onto its seat before the intake valve is opened. When the intake valve opens, air from the reservoir is allowed to flow through the brake valve to the brake chambers to apply the brakes. When the air pressure below the diaphragm overcomes the mechanical force exerted on top of the diaphragm, the diaphragm lifts sufficiently to close the intake valve and maintain the system in the holding position. Further depression of the pedal puts additional mechanical force on the diaphragm, thereby allowing further brake application. If the driver releases the brake pedal, reducing the mechanical force on the diaphragm, the inlet valve remains closed while the exhaust valve opens to allow the air under pressure to be exhausted from the brake chambers to release the brakes.

d. Brake Chamber. The brake chamber (fig. 530) converts the energy of the compressed air into mechanical force to operate the brakes. Air under pressure enters the brake chamber behind the diaphragm and forces the push rod out against the return spring force. Since the yoke on the end of the push rod is connected to the slack adjuster, this movement rotates the slack adjuster, brake camshaft, and cam to apply the brakes.

e. Quick Release Valve.

(1) *Description.* The quick release valve is provided to reduce the time required to release the brakes by hastening the exhaust of air under pressure from the brake chambers.

(2) *Operation.* The valve contains a spring-loaded diaphragm so arranged as to permit air flow through the valve in only one direction. In the brake application position, air under pressure from the brake valve enters the inlet port (fig. 531). The diaphragm is forced downward and closes the exhaust port. The air under pressure then deflects the outer edges of the diaphragm downward and

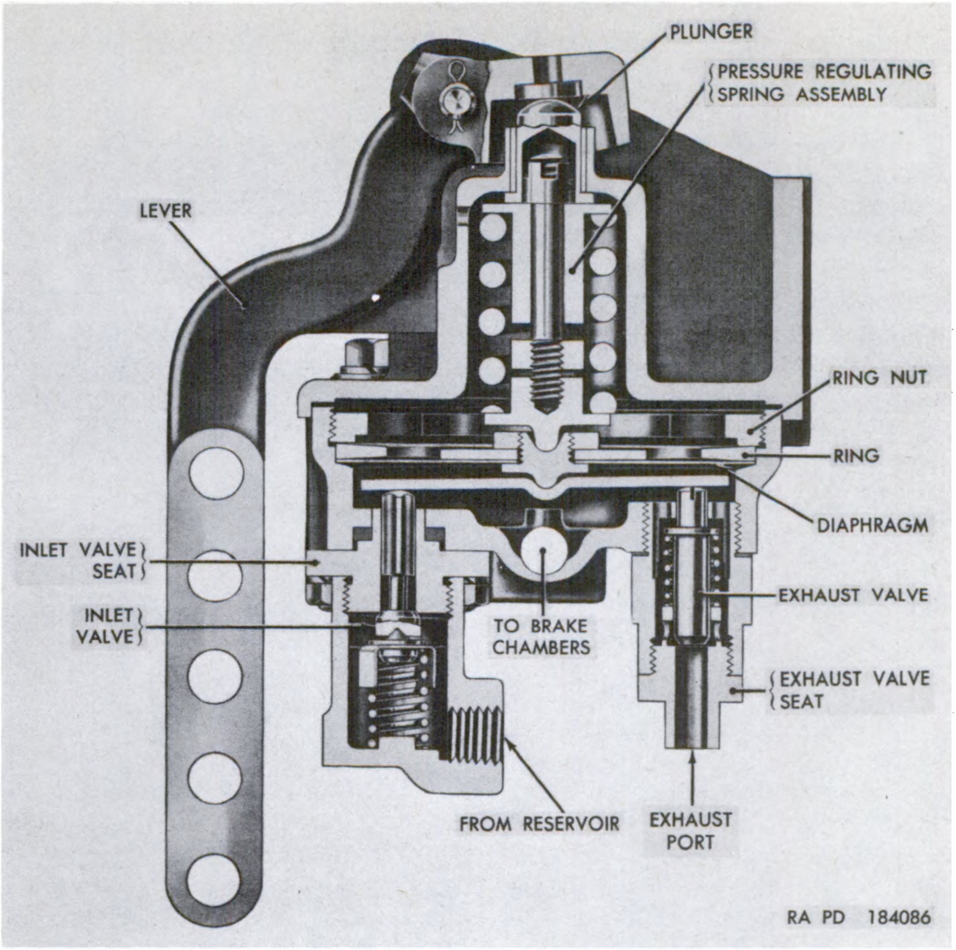

PLUNGER
PRESSURE REGULATING SPRING ASSEMBLY
LEVER
RING NUT
RING
DIAPHRAGM
INLET VALVE SEAT
EXHAUST VALVE
INLET VALVE
TO BRAKE CHAMBERS
EXHAUST VALVE SEAT
FROM RESERVOIR
EXHAUST PORT
RA PD 184086

Figure 529. Air brake valve—cross sectional view.

enters the brake chambers to apply the brakes. As soon as the air pressure in the chambers and below the diaphragm equals the air pressure above the diaphragm, the diaphragm spring forces the outer edge of the diaphragm up against the valve body, closing off the brake chambers from the inlet port. In this holding position, the diaphragm continues to keep the exhaust valve closed. If the pressure above the diaphragm is reduced or completedy released by the driver releasing the brake pedal partially or completely, the air pressure below the diaphragm causes the diaphragm to be raised to open the exhaust port and release the brake chamber air pressure.

f. Relay Valve.

(1) *Description.* The relay valve (fig. 532) is controlled by the brake valve, and speeds up application and release of the rear wheel brakes for long wheelbase vehicles. It reacts quickly to slight changes in air pressure from the brake valve.

(2) *Operation.* When the brake pedal is operated, air under pressure from the brake valve is delivered through the port

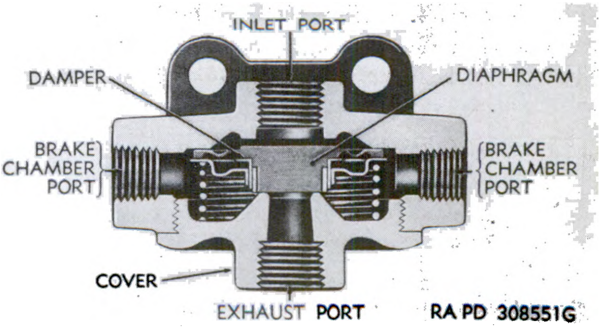

INLET PORT
DAMPER
DIAPHRAGM
BRAKE CHAMBER PORT
BRAKE CHAMBER PORT
COVER
EXHAUST PORT
RA PD 308551G

Figure 530. Brake chamber—partially cutaway view.

to the cavity above the diaphragm (fig. 532). Since this cavity is comparatively small, it is subject to quick changes in air pressure, causing the valve to react quickly. Operation of the valve is similar to that of the quick release valve (*e*(1) above). Air pressure from the brake valve forces the diaphragm down to close the exhaust port beneath the diaphragm outer edge. Further air pressure depresses the center of the diaphragm, opening the supply valve, and compressed air flows into the cavity below the diaphragm and into the brake chambers. As soon as the air pressure above the diaphragm is equalized by the brake chamber air pressure, the diaphragm is raised to the holding position, closing the supply valve and keeping the

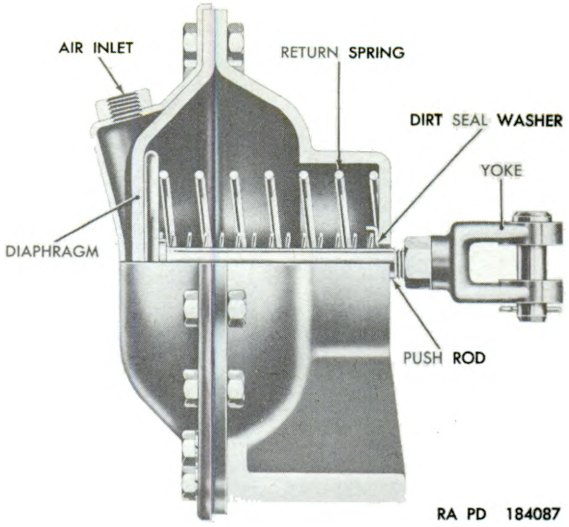

AIR INLET
RETURN SPRING
DIRT SEAL WASHER
YOKE
DIAPHRAGM
PUSH ROD
RA PD 184087

Figure 531. Quick release valve—cross sectional view.

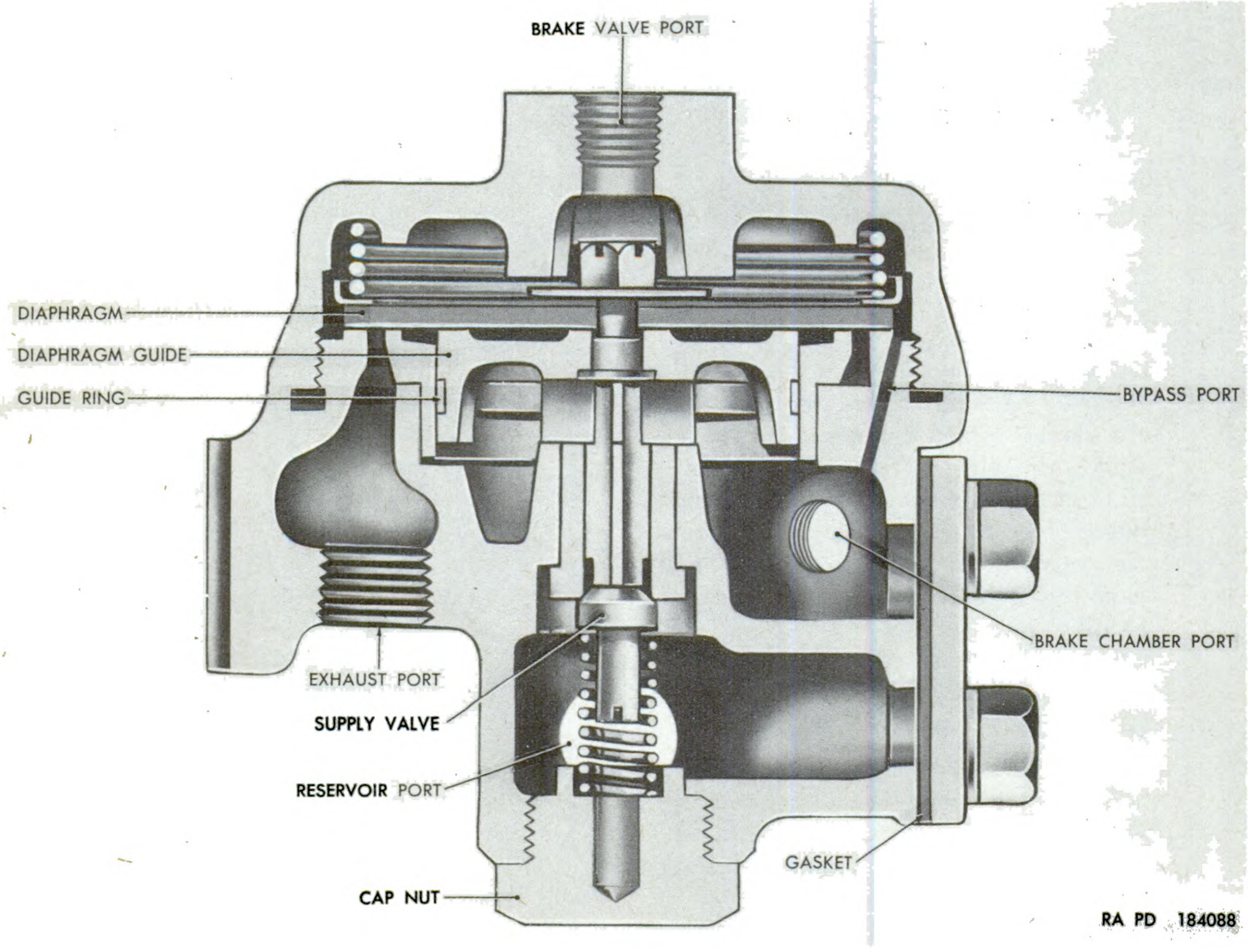

BRAKE VALVE PORT
DIAPHRAGM
DIAPHRAGM GUIDE
GUIDE RING
BYPASS PORT
BRAKE CHAMBER PORT
EXHAUST PORT
SUPPLY VALVE
RESERVOIR PORT
GASKET
CAP NUT
RA PD 184088

Figure 532. Relay valve—cross sectional view.

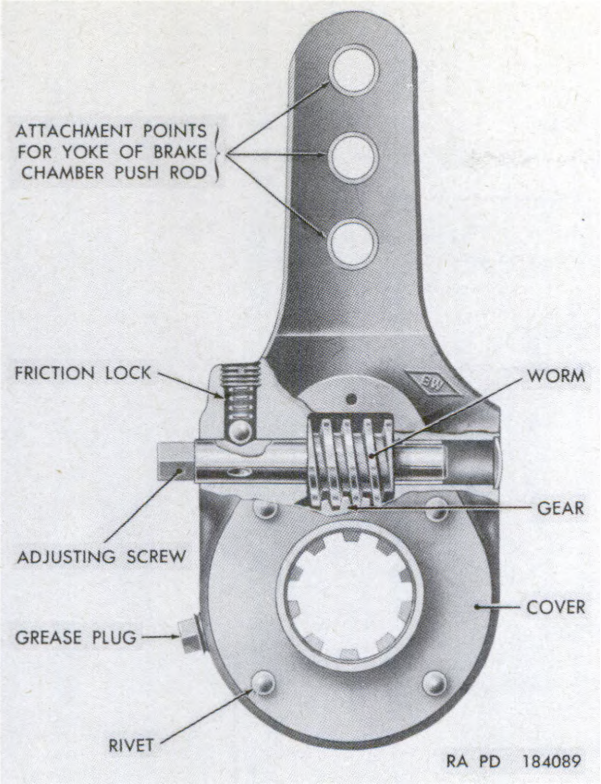


Figure 533. Slack adjuster—partially cutaway view.

exhaust port closed. When the air pressure above the diaphragm is reduced by the operator releasing the brake pedal, the brake chamber air pressure lifts the diaphragm, opening the exhaust port and exhausting the compressed air pressure from the brake chamber.

g. Slack Adjusted (fig. 533). Slack adjusters function as adjustable levers and provide a means of adjusting the brakes to compensate for wear of linings. During brake operation, the entire slack adjuster rotates with the brake camshaft which is connected to the slack adjuster through the splined central hole. For brake adjustment, the worm moves the gear, changing the position of the lever arm with respect to the camshaft.

306. Air-Over-Hydraulic Brake System

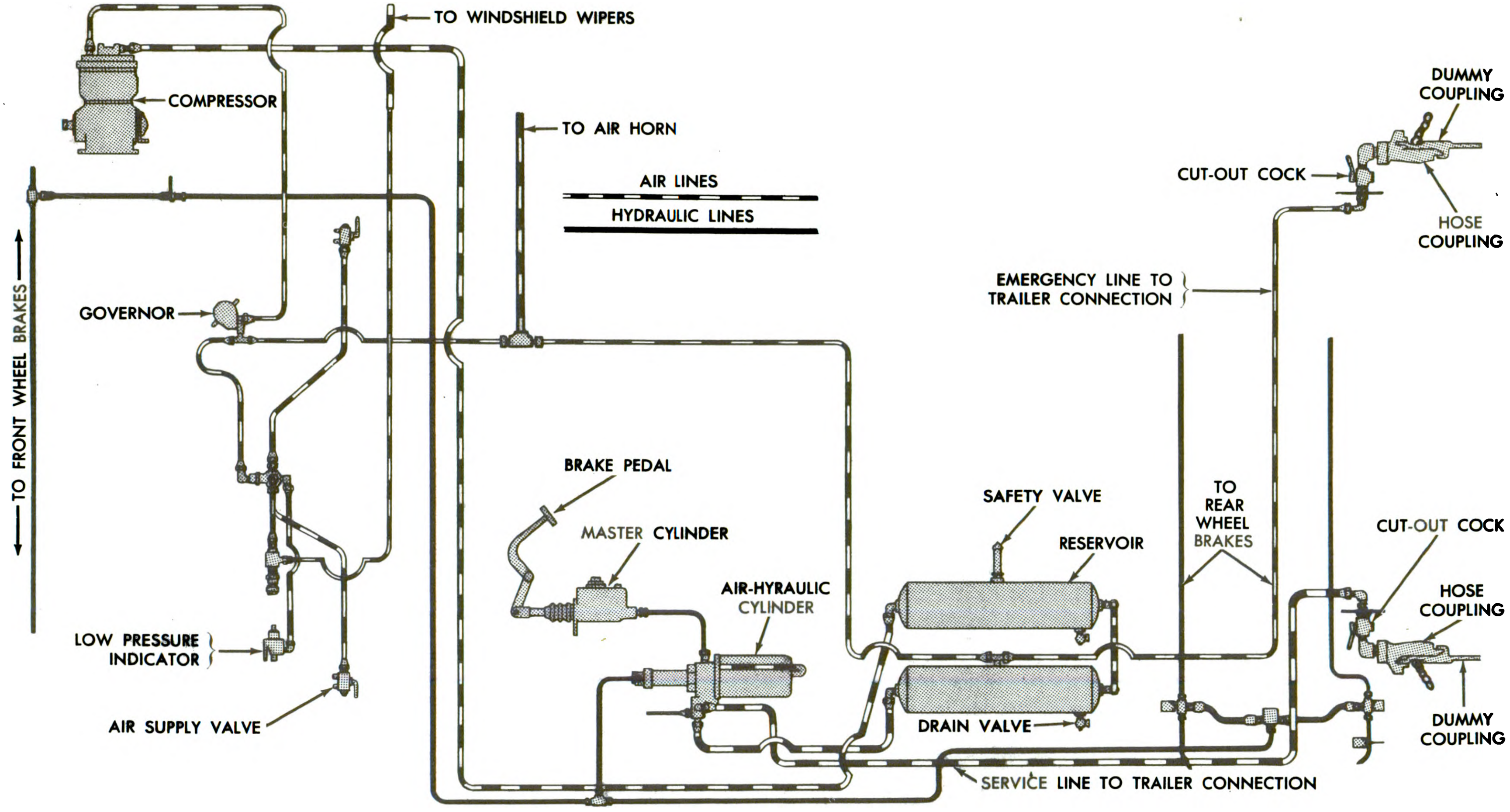
a. General. The air-over-hydraulic brake system uses the principle of the hydraulic brake (pars. 296 and 297) to operate the wheel brake cylinders and produce braking action. However, the hydraulic pressure for the wheel brake cylinders is not supplied from the master cylinder. Instead, there are two circuits. The first leads from the air-hydraulic cylinder, and admits air pressure which actuates this cylinder by moving an air piston that is connected to a hydraulic piston. The hydraulic piston then applies the hydraulic pressure that produces the braking action. The air is admitted by the action of valves controlled by the hydraulic pressure from the master cylinder.

b. Construction. The air-over-hydraulic brake system is shown in figure 534. Air pressure is supplied by a compressor and stored in reservoirs as with the air brake system (pars. 304 and 305). The master cylinder is similar to the master cylinders used in hydraulic brakes (par. 298). Also, the wheel brake cylinders and wheel brake construction are very similar to that used in hydraulic brakes. The essential difference between the straight hydraulic brake system and the air-over-hydraulic brake system lies in the air-hydraulic cylinder. This cylinder consists of three essentials: a large-diameter air piston; a small-diameter hydraulic piston in tandem with it, both on the same rod; and a set of valves controlled by hydraulic pressure from the master cylinder for admitting air into the air-cylinder section of the air-hydraulic cylinder.

c. Operation.

(1) The air-hydraulic cylinder (fig. 535) embodies an air cylinder and a hydraulic cylinder in tandem, each fitted with a piston with a common piston rod between. The air piston is of greater diameter than the hydraulic piston. This difference in areas of the two pistons gives a resultant hydraulic pressure much greater than the air pressure admitted to air cylinder. Automatic valves, actuated by fluid pressure from master cylinder, control the air admitted to air cylinder. Thus the fluid pressure in brake lines is always in a direct ratio to foot pressure on brake pedal. An air line from air-hydraulic cylinder leads to a trailer coupling at rear of vehicle.

(2) Valve action varies with the amount of brake pedal pressure, as mentioned in paragraph 305*c*. When heavy brake pedal pressure is applied by the driver for hard braking, the hydraulic pressure in the master cylinder (which operates the valves) causes greater valve movement, and therefore the valves admit more air


TO WINDSHIELD WIPERS
COMPRESSOR
TO AIR HORN
AIR LINES
HYDRAULIC LINES
DUMMY COUPLING
CUT-OUT COCK
HOSE COUPLING
EMERGENCY LINE TO TRAILER CONNECTION
TO FRONT WHEEL BRAKES
GOVERNOR
BRAKE PEDAL
MASTER CYLINDER
SAFETY VALVE
RESERVOIR
TO REAR WHEEL BRAKES
CUT-OUT COCK
HOSE COUPLING
AIR-HYRAULIC CYLINDER
LOW PRESSURE INDICATOR
AIR SUPPLY VALVE
DRAIN VALVE
DUMMY COUPLING
SERVICE LINE TO TRAILER CONNECTION

RA PD 184090

Figure 534. *Air-over-hydraulic braking system—diagrammatic view.*

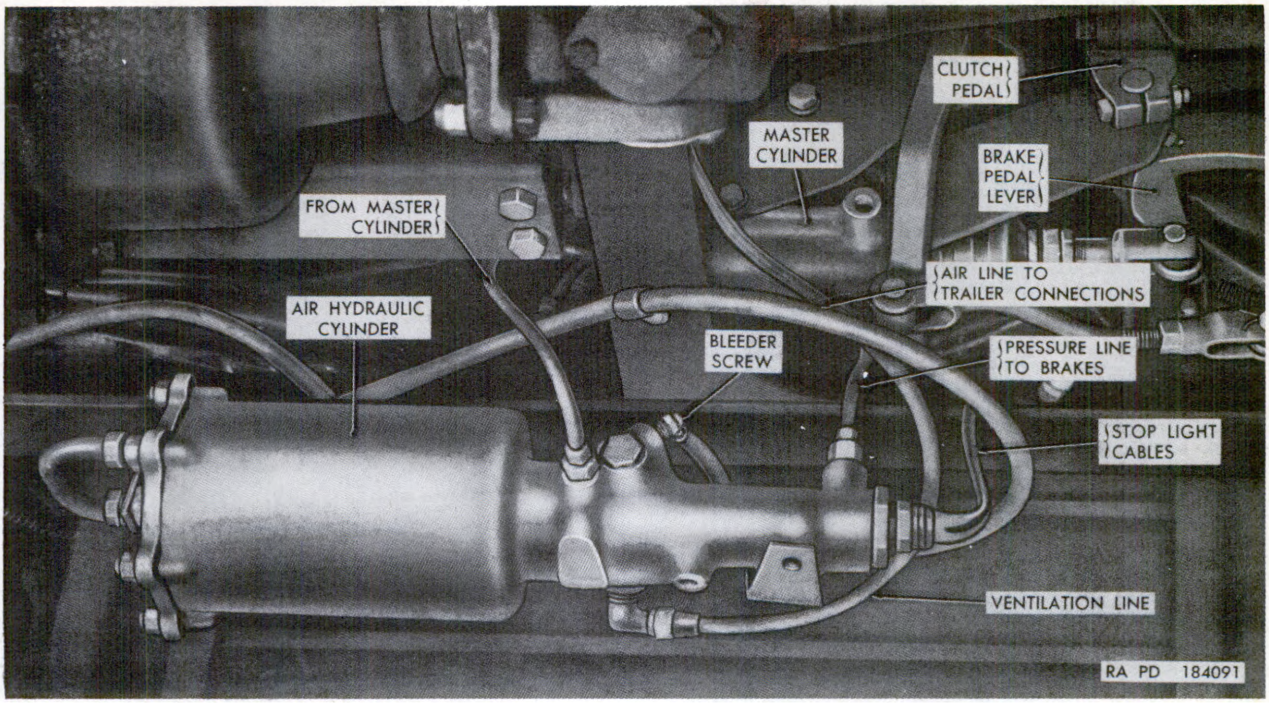


Figure 535. Air-hydraulic cylinder installed in vehicle.

pressure into the air-hydraulic cylinder. This higher air pressure causes a stronger braking action. With only a light brake pedal pressure, the valves admit less air pressure into the air-hydraulic cylinder and the braking action is lighter.

307. Vacuum Brake System

a. Principle.

(1) In order to understand the principle on which the vacuum brake system operates, it is necessary to know what a vacuum is and how it can be used. For practical purposes, a vacuum may be defined as a space from which air or gas has been partially exhausted.

(2) Air, like all matter, has weight. Since air extends upward from sea level for several hundred miles, the weight of this air exerts a pressure (termed *atmospheric pressure*) at sea level of 14.7 psi. This pressure is equally distributed in all directions upon all objects of the earth's surface. See paragraph 10*c* for a discussion of atmospheric pressure and vacuum.

(3) Atmospheric pressure may be used to operate brakes by the creation of a vacuum. Since a vacuum is created by removing air, the pressure within a vacuum is less than that of the atmosphere. A perfect vacuum from which all matter has been removed has no weight or pressure. A perfect vacuum is never obtainable, although it can be closely approached. Hence, the full force of 14.7 psi atmospheric pressure can never be utilized. If air in a container has been pumped out, or evacuated, until only 5 psi pressure remains, the psi differential existing between vacuum pressure and atmospheric pressure may be used to perform work.

(4) Vacuum is created in the intake manifold of an internal combustion engine by the pumping action of the pistons. When the vehicle is coasting in high gear with the carburetor throttle fully closed, very little air is admitted into the intake manifold, so that the pumping action of the pistons reduces the pressure to about 5 psi in the manifold. The driver's foot is taken off the accelerator pedal when he applies the brakes so that the difference between the vacuum pressure and atmospheric pressure (about 10 psi) is available to operate the brakes.

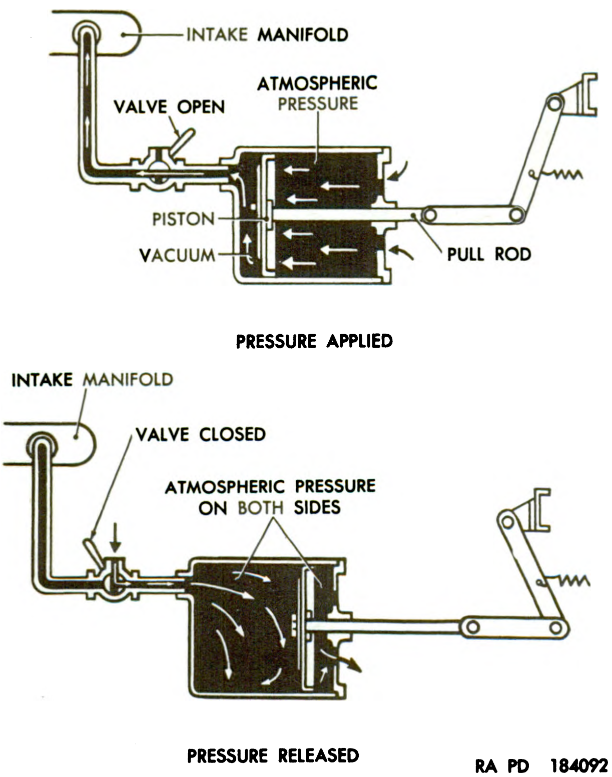

INTAKE MANIFOLD
ATMOSPHERIC PRESSURE
VALVE OPEN
PISTON
VACUUM
PULL ROD
PRESSURE APPLIED
INTAKE MANIFOLD
VALVE CLOSED
ATMOSPHERIC PRESSURE ON BOTH SIDES
PRESSURE RELEASED
RA PD 184092

Figure 536. Action of vacuum power brake cylinder.

b. Power Cylinder.

(1) Any chamber connected to the intake manifold will have air exhausted from it when the engine is running. The power cylinder, which contains a piston, depends upon this fact for its operation. A valve (fig. 536) operated by the brake pedal is inserted between the cylinder and manifold, to control the operation of the power cylinder. When the valve is opened, air is exhausted from the chamber ahead of the piston. Atmospheric pressure acts on the other side of the piston to exert a powerful force on the rod attached to the piston. The amount of force depends on the area of the piston on which the pressure acts.

(2) When the valve is closed, the chamber ahead of the piston is shut off from the intake manifold and connected to the atmosphere. Air enters this chamber through the valve and raises the pressure on the front side of the piston to that of the atmosphere, as shown in the lower illustration of figure 536. The pressure is then the same on both sides of the piston so that no force is exerted on the pull rod and it remains in the release position. The operating principle of the brake valve in a vacuum brake system is similar to that shown in figure 536, although the internal construction and operation are quite different.

c. Atmospheric Suspended Brake System (fig. 537).

(1) In the power brake cylinder shown in figure 536, atmospheric pressure exists on both sides of the piston when the valve is closed. A braking system with the power cylinder operated in this manner is known as an *atmospheric suspended brake system.* Depressing the brake pedal opens the brake valve, giving a free passage from the front chamber of the power cylinder to the intake manifold. (The piston pull rod end of the cylinder is designated as "rear" and the opposite end as "front.") The power of a vacuum cylinder may be applied to either mechanical or hydraulic brake systems.

(2) The vacuum power cylinder supplies a considerable force to augment, or "boost," the force of the driver's foot. For this reason, the vacuum power brake is often called a *booster brake.* If the vacuum power system fails, the brakes can still be operated by application of force on the brake pedal. However, without the booster effect, the driver must apply a much greater force to attain comparable braking effect.

d. Vacuum Suspended Brake System (fig. 538).

(1) In order to apply the brakes faster and to take advantage of the vacuum available for operating the brakes, a vacuum

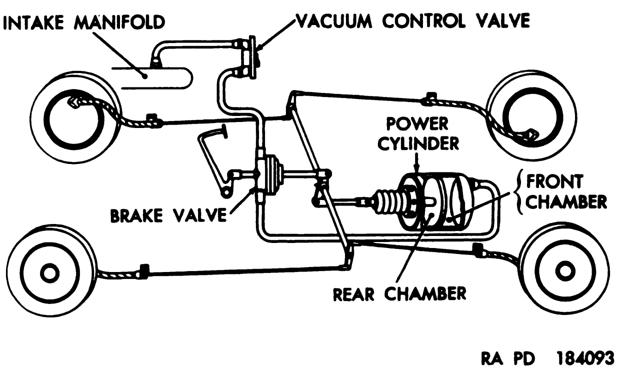

INTAKE MANIFOLD
VACUUM CONTROL VALVE
POWER CYLINDER
FRONT CHAMBER
BRAKE VALVE
REAR CHAMBER
RA PD 184093

Figure 537. Atmospheric suspended brake system.

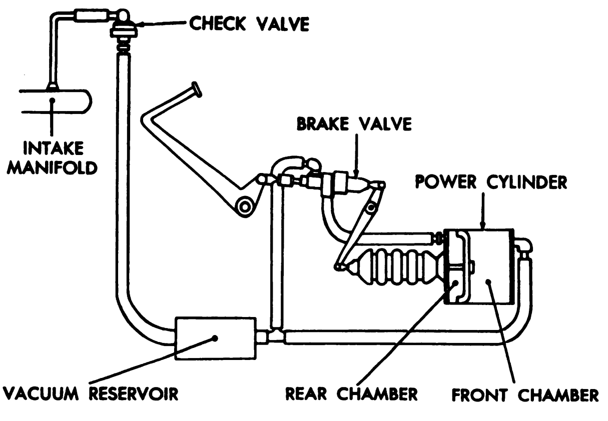


Figure 538. Vacuum suspended brake system.

system has been developed in which vacuum is present on both sides of the piston when the engine is running and brakes are released. Such a vacuum system of power braking is known as a *vacuum suspended brake system.* Figure 539 shows the power cylinder used in this system.

(2) A check valve maintains a vacuum within the system, even after the engine is stopped, by closing the intake manifold when pressure in the manifold rises above the vacuum pressure within the system. A vacuum reservoir is usually required so that a substantial source of vacuum is available. Once air is pumped out of the vacuum reservoir through the intake manifold, the resulting vacuum is diminished only by operating the power cylinder.

(3) With the brake pedal in the release position, there is a passage through the brake valve from the vacuum reservoir to the rear chamber of the power cylinder. Since the front chamber is connected to the vacuum reservoir at all times, the piston is suspended in a vacuum when it is in the release position.

(4) When the brake pedal is depressed to apply the brakes, the brake valve closes the vacuum passage to the rear chamber and opens a passage to the atmosphere through the brake valve. Air is admitted only to the rear chamber, which is considered the pressure chamber. The piston is thus forced to the front of the power cylinder to apply power to the braking system. With the vacuum suspended system, the brakes may be applied without admitting a charge of air to the vacuum reservoir, so that the available vacuum is not reduced.

(5) When the brake pedal is released, the air in the rear chamber of the power cylinder is drawn into the vacuum reservoir through a passage opened in the brake valve, equalizing pressure on each side of the piston and permitting the brakes to be released by their retracting springs.

(6) All force applied to the brake pedal is transmitted directly to the brake system, since the brake valve is contained within the pull rods that operate the brake mechanism. The entire valve may be moved with the pull rods to apply the brakes by physical effort when the power cylinder becomes inoperative.

e. Slide-Valve-Reaction Internal-Valve Brake Power Unit.

(1) This type of power unit (fig. 539) has an internal control valve piston in the hollow piston rod, and is actuated by external pedal linkage. It is termed *reaction* type because it transmits an opposing force to the pedal against applied foot pressure, resulting in what is known as *pedal feel*, or reaction. The reaction furnishes the driver with an indication of the extent of brake application and permits close control of braking operation.

(2) In the released position, the atmospheric port and the vacuum (fig. 540) in the piston rod are uncovered by the internal control valve piston so that there is an uninterrupted connection between the front and rear compartments of the power unit. Since the rear compartment is connected to the vacuum source, there will also be vacuum in the front compartment so that the vacuum piston will remain inoperative. The vacuum piston return spring (fig. 539) holds the vacuum piston in the released position, and the internal control and valve piston return spring (fig. 540) holds the control valve piston in the released position. Air at atmospheric pressure is always present inside the hollow piston rod, as port holes on the clevis, or yoke, end of the

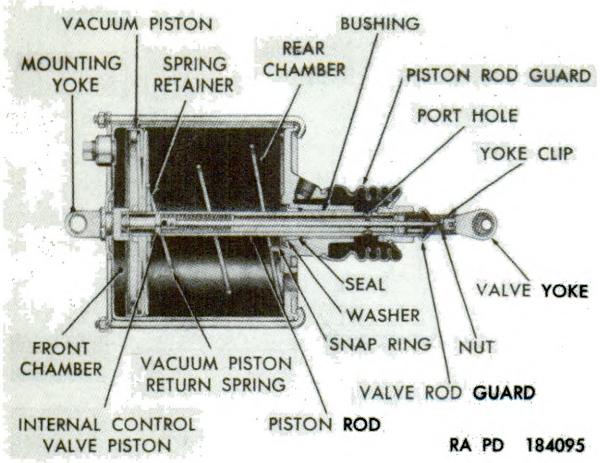


***Figure 539.** Slide-valve-reaction internal-valve brake power unit.*

piston rod (fig. 539) are directly connected to the air cleaner and atmospheric inlet.

(3) When the foot pedal is depressed, the operating linkage moves the valve rod (fig. 540) outward from the power unit. This movement first causes the internal control valve piston to cover the atmospheric port in the piston rod, sealing off the connection between the two sides of the vacuum piston. The internal control-valve piston slides within the piston rod beyond the atmospheric port, allowing air from the air cleaner to pass through the port holes in the yoke end of the piston rod (fig. 539), the hollow piston rod, and ports in the internal control valve piston (fig. 540), and then out into the front compartment which remains sealed off from the rear, or vacuum, compartment. The atmospheric pressure on the front side of the vacuum piston (fig. 539) causes it (and the piston rod) to move toward the vacuum side. The piston rod, which is connected to the brake linkage, assists the foot pedal in applying the brakes.

(4) In the holding, or partially applied "lap" position, with the brake pedal partially depressed and then held stationary, the vacuum piston (fig. 539) will move until it positions itself at the point where the internal control valve piston just covers the atmospheric port and where the slightest travel of the valve rod will uncover the ports either to the atmosphere or the vacuum.

f. Poppet-Valve-Reaction Internal-Valve Brake Power Unit.

(1) The front chamber (fig. 541) of the power unit is connected directly to the vacuum source. In the released position, with the vacuum valve (fig. 542) off its seat, the opening at the center of the piston rod allows vacuum to be present also on the rear side of the piston so that the piston will remain inoperative. A conical return spring holds the piston in the released position and the valve rod spring holds the valve in the off (released) position. Air from the air cleaner is admitted into the hollow piston rod through the rubber guard and port holes near the end of the rod.

(2) When the foot pedal is depressed, the operating linkage moves the valve rod toward the power unit. This movement first seats the vacuum valve, sealing off the connection between the two sides of the piston, and then causes the atmospheric valve to leave its seat, allowing air from the hollow piston rod to enter the rear compartment of the cylinder. Atmospheric pressure on the rear side moves the piston toward the vacuum side. The power-cylinder piston rod is connected to the brake linkage and assists the foot pedal in applying the brakes.

(3) In the holding, or partially applied "lap" position, when the brake pedal is partially depressed and then held stationary, the piston will move and position itself at the point where both the vacuum and atmospheric valves are on their respective seats. The slightest movement of the brake pedal, and consequently of the valve rod, will open either one of the two valves and slightly release the brakes or apply them farther, depending on the direction of motion.

g. Hydrovac Vacuum Power Brake Cylinder.

(1) *Hydrovac* is a trade name for a one-unit, vacuum power braking system. It combines into one assembly a hydraulically actuated control valve (fig. 543) (as contrasted with the internal valve brake

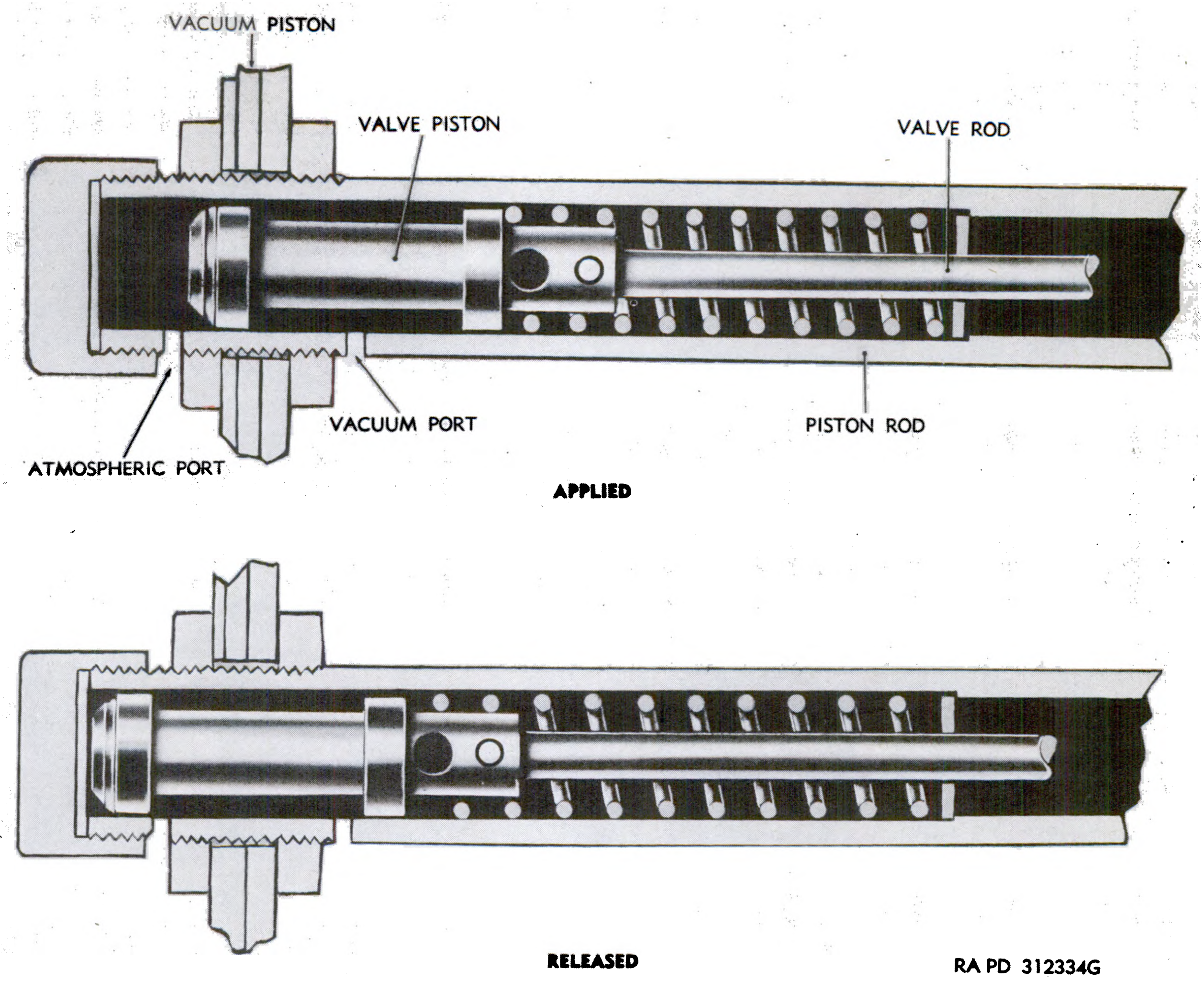

VACUUM PISTON
VALVE PISTON
VALVE ROD
VACUUM PORT
PISTON ROD
ATMOSPHERIC PORT
APPLIED
RELEASED
RA PD 312334G

Figure 540. Operation of internal control valve piston of slide-valve-reaction internal-valve brake power unit.

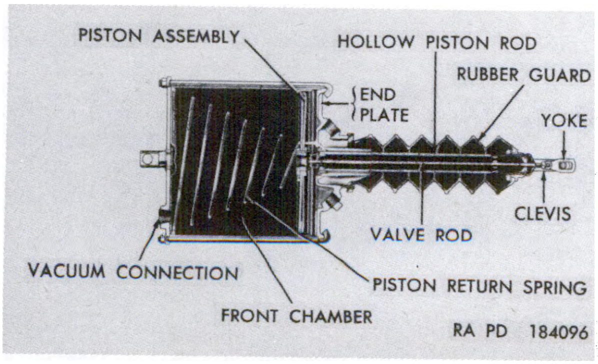
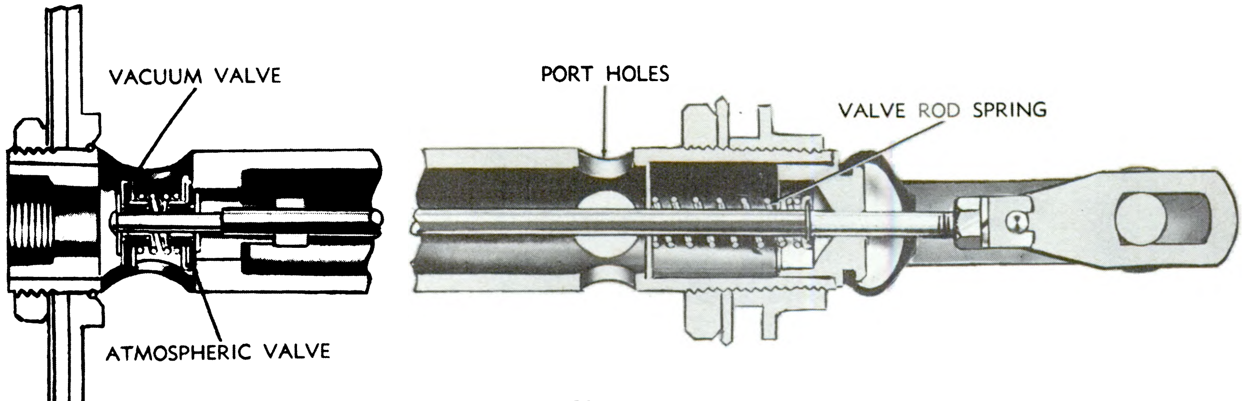

PISTON ASSEMBLY
HOLLOW PISTON ROD
RUBBER GUARD
END PLATE
YOKE
CLEVIS
VALVE ROD
VACUUM CONNECTION
PISTON RETURN SPRING
FRONT CHAMBER
RA PD 184096

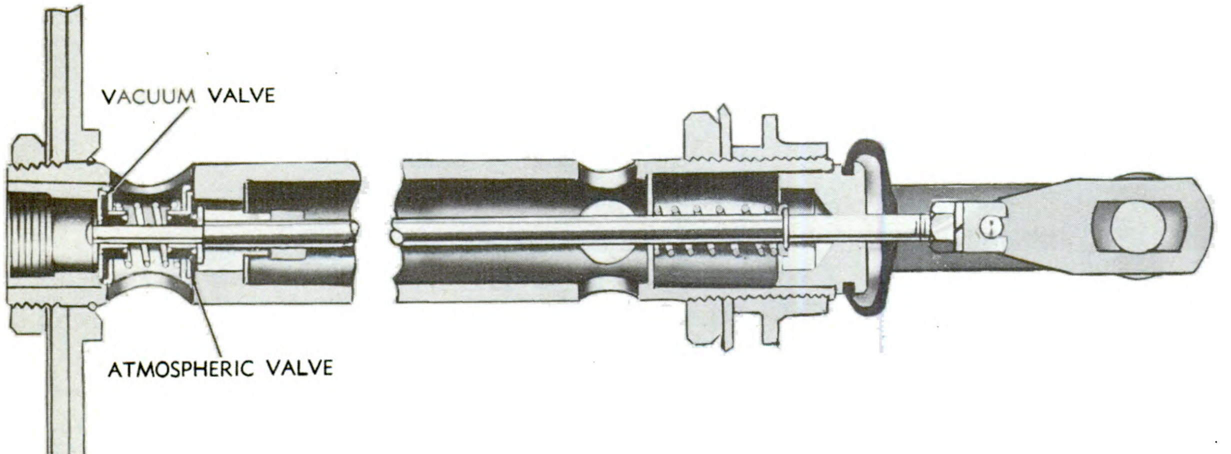
Figure 541. Poppet-valve-reaction internal-valve brake power unit.

power units, covered in *e* and *f* above, whose control valves are mechanically connected to the brake linkage), a tandem piston vacuum power cylinder, and a hydraulic slave cylinder. It is connected hydraulically to both the master cylinder and the wheel brakes, eliminating the need for mechanical connections with the brake pedal and linkage.

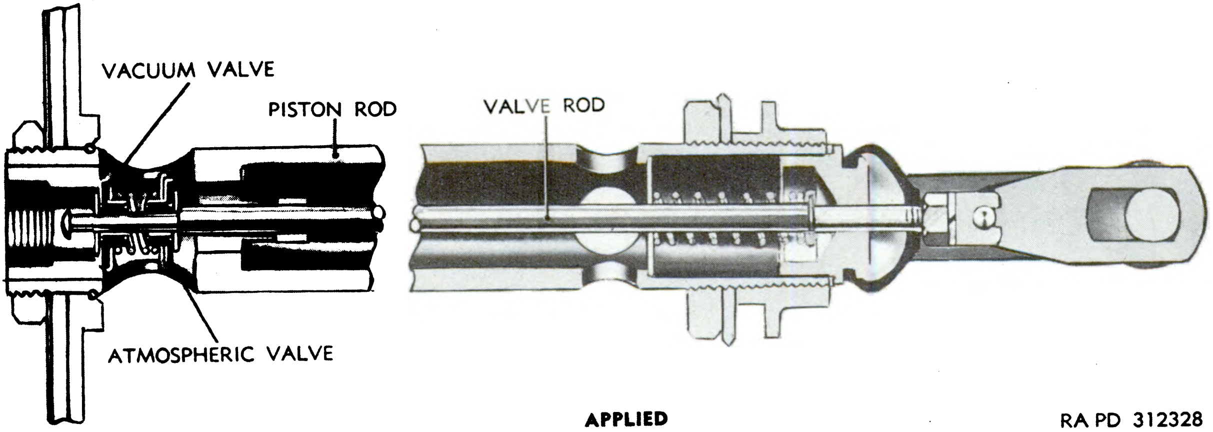
(2) The vacuum power cylinder is divided into four compartments by the front and rear pistons and the center plate (fig. 544). The vacuum source is directly connected to the compartment between the center plate and rear piston. The vacuum is connected from this compartment, by means of the vacuum line, to the relay or control valve. From the control valve, the vacuum is connected to the front compartment by a passage in the valve body. In the released position, with the control valve diaphragm plate


VACUUM VALVE
PORT HOLES
VALVE ROD SPRING
ATMOSPHERIC VALVE

RELEASED


VACUUM VALVE
ATMOSPHERIC VALVE

PARTIAL APPLICATION


VACUUM VALVE
PISTON ROD
VALVE ROD
ATMOSPHERIC VALVE
RA PD 312328

APPLIED

Figure 542. Operation of valve rod of poppet-valve-reaction internal-valve brake power unit.

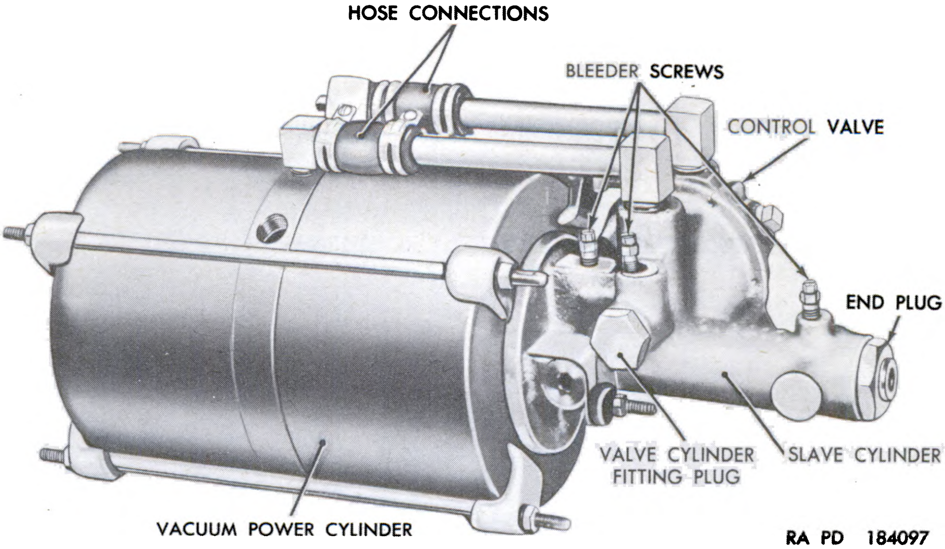


Figure 543. Hydrovac vacuum power brake cylinder.

and the vacuum valve seat held down by the valve spring to keep the vacuum valve open and the atmospheric valve closed, the vacuum is connected through the vacuum valve and atmospheric control line to the compartment between the center plate and front piston and thence, through the ports in the hollow piston rod, to the rear compartment. Vacuum is therefore present in all four compartments in the released position and both pistons remain inoperative. The piston return spring holds the pistons in the OFF position. The push rod, in the released position, maintains the bypass (check) valve off its seat, permitting a direct hydraulic connection from the master cylinder, through the hydraulic slave cylinder, to the wheel cylinders. With this construction, foot pedal pressure can be applied to the wheel cylinders for braking action should vacuum or Hydrovac failure make the power cylinder inoperative The relay valve diaphragm has vacuum on both sides and is held in the OFF position by the valve spring. When the vacuum in the Hydrovac is the same as, or greater than, the source vacuum, the poppet valve in the vacuum check valves rests on its seat and, in the event of engine failure or rapid acceleration, traps the vacuum in the Hydrovac system in readiness for brake application.

(3) As the foot pedal is depressed, fluid is forced from the master cylinder through the open bypass (check) valve to the slave cylinder and on to the wheel cylinders. The fluid is also forced through the drilled bypass passage to the relay valve hydraulic piston, which is forced outward against the pressure of the valve spring, gradually forcing the diaphragm plate and vacuum valve seat toward the applied position. The movement of the diaphragm first closes the vacuum valve against its seat, sealing off the vacuum from the atmospheric control line. After the vacuum valve is seated, further motion of the diaphragm causes the atmospheric valve to leave its seat, permitting air from the air cleaner to enter the atmospheric control line, thence to the compartment between the center plate and front piston and, through the hollow piston rod, to the rear compartment (fig. 545). With the vacuum still present on the front sides of both pistons and atmospheric pressure on the rear sides of both pistons, the pistons are caused to move toward the slave cylinder by the difference in pressure. Movement of the pistons and push rod toward the slave-

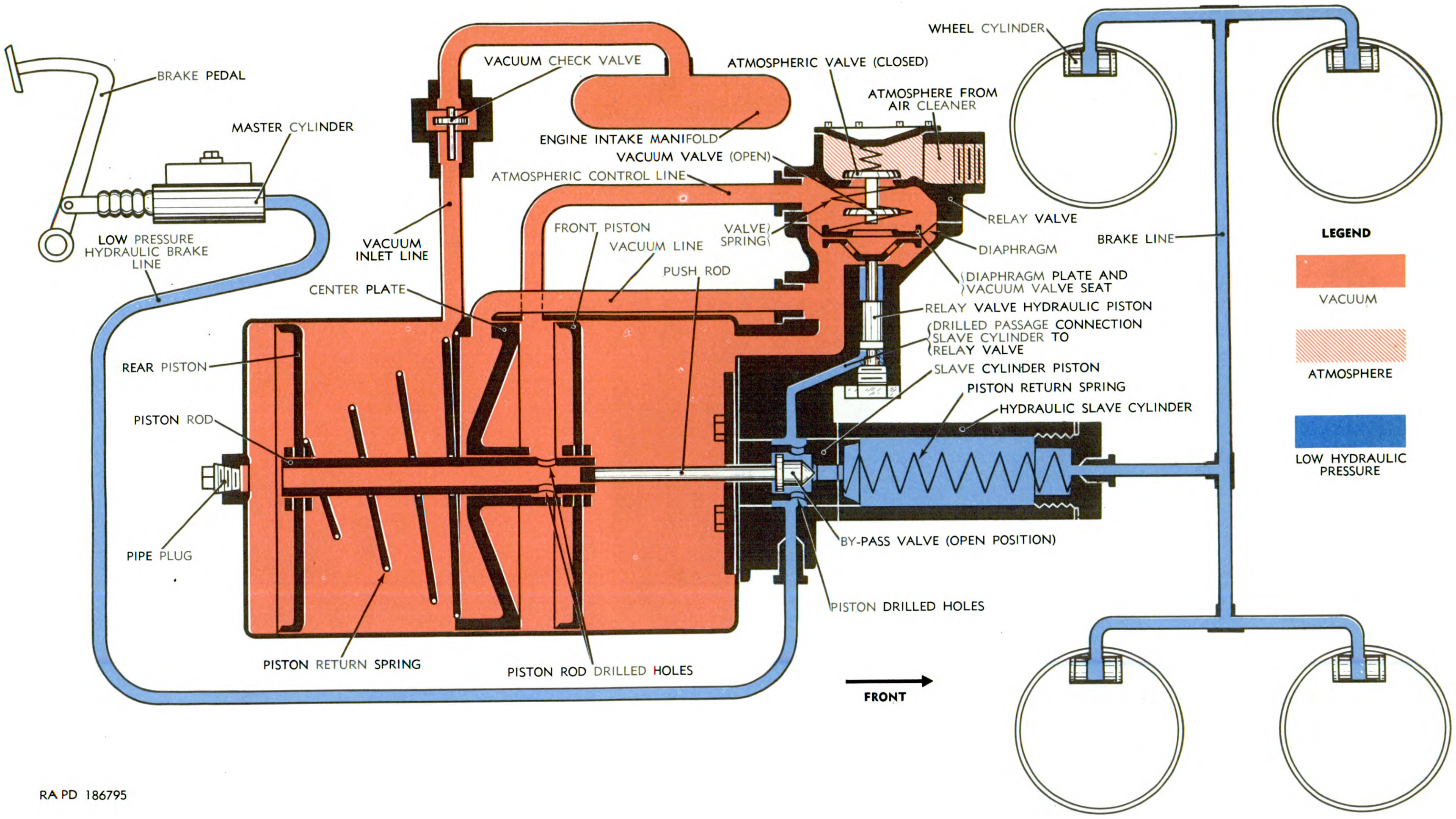
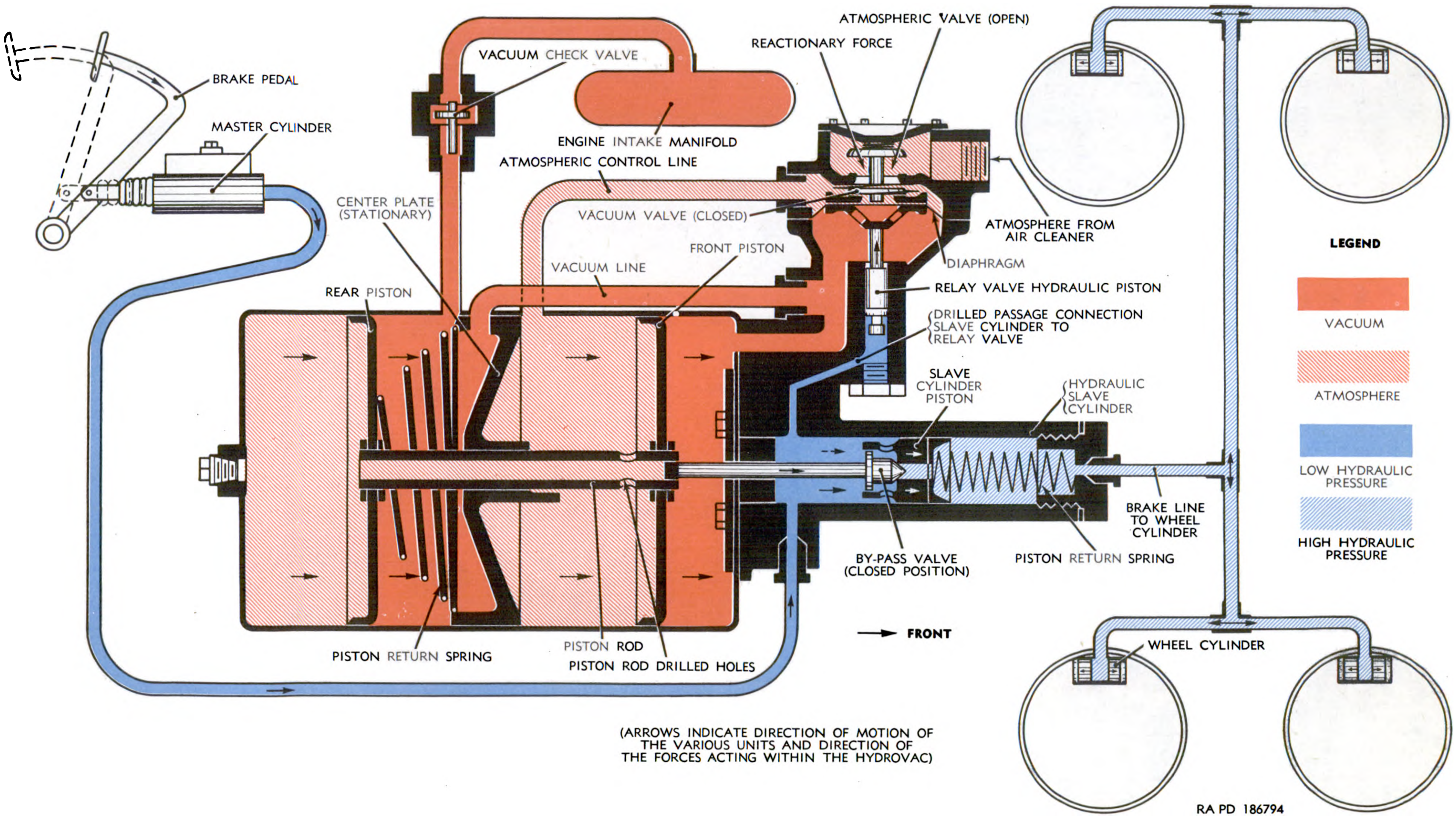

WHEEL CYLINDER
ATMOSPHERIC VALVE (CLOSED)
ATMOSPHERE FROM AIR CLEANER
BRAKE PEDAL
VACUUM CHECK VALVE
MASTER CYLINDER
ENGINE INTAKE MANIFOLD
VACUUM VALVE (OPEN)
ATMOSPHERIC CONTROL LINE
RELAY VALVE
FRONT PISTON
VALVE SPRING
VACUUM LINE
LOW PRESSURE HYDRAULIC BRAKE LINE
VACUUM INLET LINE
DIAPHRAGM
BRAKE LINE
PUSH ROD
DIAPHRAGM PLATE AND VACUUM VALVE SEAT
CENTER PLATE
RELAY VALVE HYDRAULIC PISTON
DRILLED PASSAGE CONNECTION SLAVE CYLINDER TO RELAY VALVE
REAR PISTON
SLAVE CYLINDER PISTON
PISTON RETURN SPRING
HYDRAULIC SLAVE CYLINDER
PISTON ROD
PIPE PLUG
BY-PASS VALVE (OPEN POSITION)
PISTON DRILLED HOLES
PISTON RETURN SPRING
PISTON ROD DRILLED HOLES
FRONT
LEGEND
VACUUM
ATMOSPHERE
LOW HYDRAULIC PRESSURE
RA PD 186795

Figure 544. Hydrovac operation—released position.


ATMOSPHERIC VALVE (OPEN)
REACTIONARY FORCE
VACUUM CHECK VALVE
BRAKE PEDAL
MASTER CYLINDER
ENGINE INTAKE MANIFOLD
ATMOSPHERIC CONTROL LINE
CENTER PLATE (STATIONARY)
VACUUM VALVE (CLOSED)
FRONT PISTON
VACUUM LINE
REAR PISTON
ATMOSPHERE FROM AIR CLEANER
DIAPHRAGM
RELAY VALVE HYDRAULIC PISTON
DRILLED PASSAGE CONNECTION SLAVE CYLINDER TO RELAY VALVE
SLAVE CYLINDER PISTON
HYDRAULIC SLAVE CYLINDER
BRAKE LINE TO WHEEL CYLINDER
BY-PASS VALVE (CLOSED POSITION)
PISTON RETURN SPRING
FRONT
PISTON RETURN SPRING
PISTON ROD
PISTON ROD DRILLED HOLES
WHEEL CYLINDER
LEGEND
VACUUM
ATMOSPHERE
LOW HYDRAULIC PRESSURE
HIGH HYDRAULIC PRESSURE
RA PD 186794

(ARROWS INDICATE DIRECTION OF MOTION OF THE VARIOUS UNITS AND DIRECTION OF THE FORCES ACTING WITHIN THE HYDROVAC)

Figure 545. ***Hydrovac operation—applied position.***

cylinder first closes the bypass (check) valve, and causes the slave-cylinder piston to move outward, forcing fluid under high pressure into the wheel cylinders to apply the brakes. The foot pedal pressure, acting through the master cylinder, also acts against the slave-cylinder piston, assisting the vacuum pistons and push rod. The pressure at the wheel cylinders (i. e., the total braking effort) is the sum of the output of the vacuum pistons in the Hydrovac and of the foot-pedal pressure at the master cylinder. Release of foot-pedal pressure allows the valve spring in the relay or control valve to return the atmospheric and vacuum valves to the released position by removing the fluid pressure from below the relay valve hydraulic piston. The atmosphere is exhausted from the rear sides of both pistons, making them inoperative and allowing the piston return spring to move the pistons to the released position.

(4) When the foot pedal movement stops at some intermediate point between the released and fully applied position, the pistons will move toward the "lap" position so that the fluid pressure under the relay-valve hydraulic piston will be reduced the necessary amount to allow the diaphragm to drop and close both the atmospheric and vacuum valves in the control valve. Thereafter, the slightest foot-pedal movement, either toward the released or the applied position, will result in the opening of either the vacuum or the atmospheric valve, and will partially release or further apply the brakes.

308. Electric Brake System

a. General. An electrically operated brake is sometimes used. The layout of the electric brake system which operates from the storage battery or the electrical system is quite simple. Wiring replaces the rods, cables, and tubings used in other types of brakes.

b. Controller. The controller can be mounted at any convenient place in the driver's compartment. It is usually attached to the steering column. A bronze lever (fig. 546) within the controller, connected by linkage to the brake pedal, acts as a rheostat switch. The controller is provided with electrical terminals to connect it in the electric brake circuit. As the brake pedal is depressed, the bronze lever comes in successive contact with leaves of varying lengths and completes the electric circuit from the battery to an electromagnet in the brake. Electric current is supplied to the electromagnet, the amount depending on the number of leaves contacted by the bronze lever. When the brake is fully depressed, all the leaves are in contact with the bronze lever and the maximum amount of current flows to the brake.

c. Electric Brake (fig. 547).

(1) The armature assembly revolves with the brakedrum, and is kept in constant contact with the electromagnet by means of flat springs. When the brake pedal is depressed, the current flows from the controller to the brake and through a coil of copper wire in the magnet, setting up a magnetic field and causing the magnet to attract the armature. The farther the foot pedal is depressed, the greater is the amount of current that reaches the magnet and the tighter the magnet clings to the armature. This attraction of the magnet to the armature causes the magnet, which can revolve within a limited arc, to start turning with the armature. As the magnet turns, it engages a cam

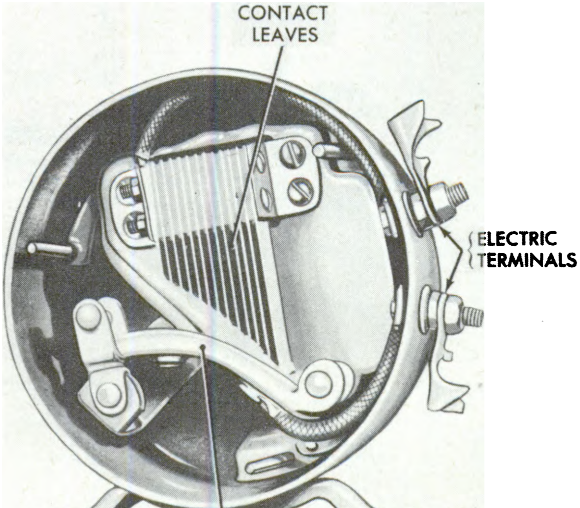
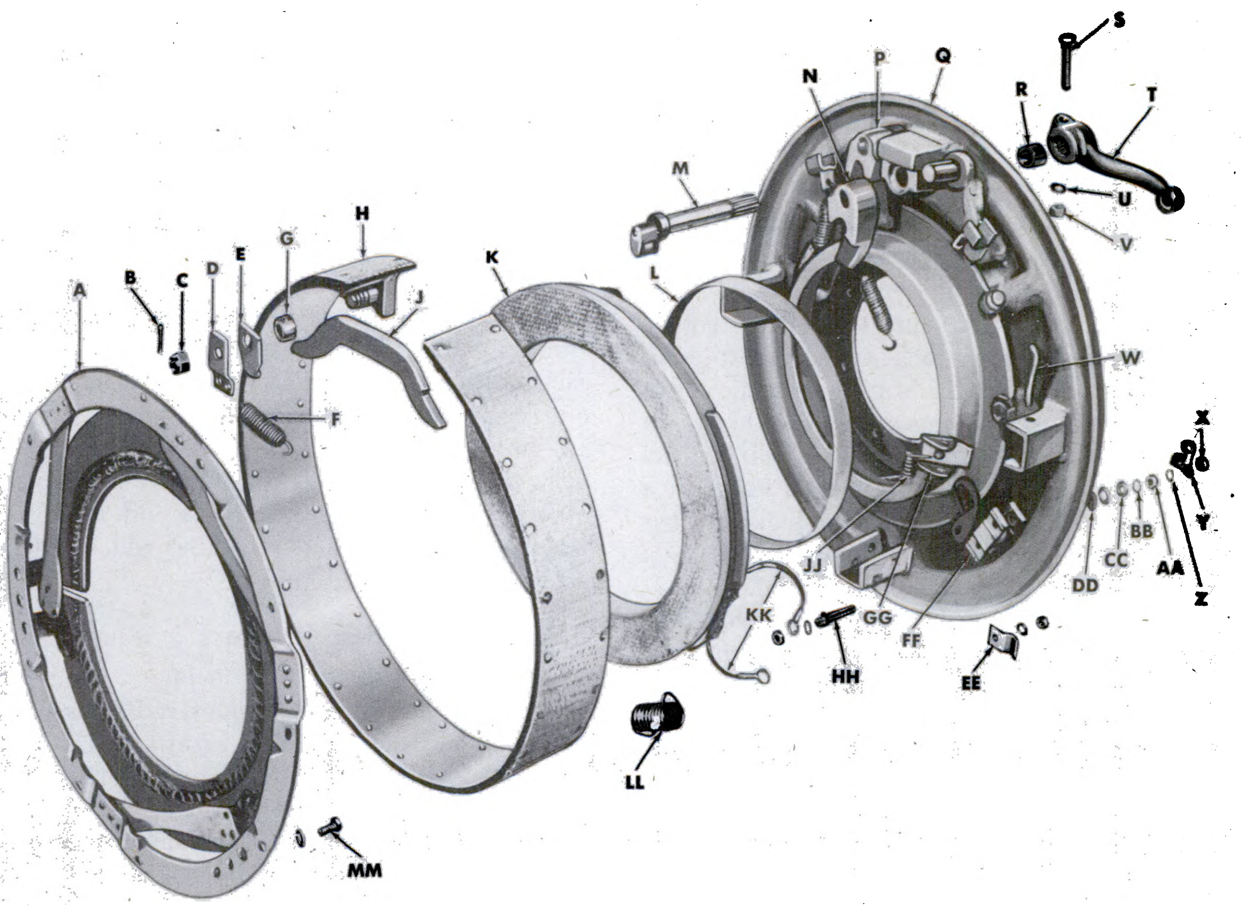


Figure 546. Controller for electric brake.



A—ARMATURE ASSEMBLY
B—COTTER PIN
C—SLOTTED NUT
D—SPRING CLIP
E—RETAINER WASHER
F—BAND RETURN SPRING
G—ROLLER
H—BAND AND LINING ASSEMBLY
J—PARKING TRUST LEVER
K—MAGNET ASSEMBLY
L—MAGNET BUSHING
M—PARKING CAMSHAFT LEVER
N—LEFT-HAND CAM
P—RIGHT-HAND CAM
Q—BACKING PLATE ASSEMBLY
R—BUSHING
S—BOLT
T—PARKING CAMSHAFT LEVER
U—LOCK WASHER
V—NUT
W—COTTER PIN
X—NUT
Y—TERMINAL
Z—LOCK WASHER
AA—NUT
BB—LOCK WASHER
CC—BRASS WASHER
DD—FIBER WASHER
EE—WIRE CLAMP
FF—INSIDE CONTACT INSULATOR
GG—MAGNETIC HOLDDOWN BAR
HH—STUD
JJ—MAGNETIC HOLDDOWN SPRING
KK—MAGNETIC WIRE
LL—MAGNETIC RETURN SPRING
MM—SCREW

RA PD 184099

Figure 547. Electric brake—disassembled view.

lever which in turn expands the brake band evenly against the brakedrum in the conventional way.

(2) When the current is cut off by removing pressure from the brake pedal, the magnet in each brake is demagnetized and remains stationary. The brake return springs release the brake bands from contact with the brake drums.

(3) The principle of the electric brake permits use of a self-adjusting feature to compensate for lining wear. As the brake band wears, the electromagnet moves a little farther to drive the brake lining against the surface of the drum. An automatic stop on the brake band prevents the rivets from coming into contact with the drum after excessive wear, eliminating danger of scoring of the drum.

(4) If the vehicle is standing still and the current is turned on, there is no action of the brakes. If the wheel revolves in the slightest degree, however, the brake is operated.

CHAPTER 22

HULLS AND FRAMES

309. Frames

The frame is a base to which the body and other units of the chassis are attached. The most essential requirement of frames is stiffness, sufficient to withstand unusual twisting under load, to absorb road shocks, and to keep the attached units in correct alinement. The plan and construction of a frame depends upon the type of vehicle and the service for which the vehicle is intended. Passenger car frames can be comparatively light because the frame receives approximately two-thirds of its rigidity from the body structure, which, in most cases, is made of steel. The metal covering the bodies of some passenger cars, delivery trucks, and buses is given a special skin stressing process; metal covering and the body framework are substituted for the vehicle frame. Attempts to strengthen the vehicle frame by increasing the size of the members is effective to only a minor degree; using the same amount of metal in strengthening the body structure is of considerable benefit. In military vehicles, standard frames ordinarily are used and also, in these vehicles, the body plays an important part in adding strength and rigidity to the frame. In tanks and certain amphibious vehicles, the hull itself serves as the frame.

310. Passenger Car Frames

Passenger car frames are built of side rails, cross members, and gussets, riveted or welded together into some form of "A," "X," "Y," or "K" construction to secure stiffness with light weight. (Gussets are angular pieces of metal for strengthening angles or corners.) Frames are usually not more than 30 inches wide in front, to permit the use of a short turning radius, and may be widened at the rear to 48 inches for increased body stability. Kickups may be provided over the axles to lower the center of gravity of the vehicle.

311. Truck Frames

Trucks of up to 1-ton capacity have frames similar to those of passenger cars. For larger trucks the frames are simple, rugged, channel-iron construction such as shown in figures 284 and 285. The side rails are usually parallel to each other at standardized SAE widths to permit the mounting of stock transmissions, transfer assemblies, rear axles, and the like. Trucks which are to be used as prime movers have an additional reinforcement of the side rails and rear cross members to compensate for the added towing stresses.

312. Brackets and Hangers

Frame members serve as supports to which springs, independent suspensions, radiators, transmissions, and the like may be attached. Additional brackets, outriggers, engine supports, and horns are added for the mounting of running boards, longitudinal springs, bumpers, engines, towing hooks, shock absorbers, gas tanks, and spare tires.

313. Hulls of Tanks and Armored Cars

A tank hull or body, welded into an assembly from heavy armor plate, serves not only as a frame, but also to house and protect the crew and equipment. Removable sections are provided for service operations; a circular opening in the top for the installation of the turret; openings in the front or rear end for the installation of the power train; and other openings for escape hatches, vision devices, and gun mountings. The interior of the hull is divided into an engine compartment and a fighting compartment by a lateral bulkhead which also strengthens the unit. The hull of an armored car is constructed in a similar manner, although of lighter weight plate, and it, also, serves as a frame for the vehicle.

314. Hulls of Cargo Carriers

Cargo carriers, including the amphibious types, utilize the hull as a frame. In both type vehicles, the hull consists of a sheet-steel welded structure, except for various covers which are easily removed

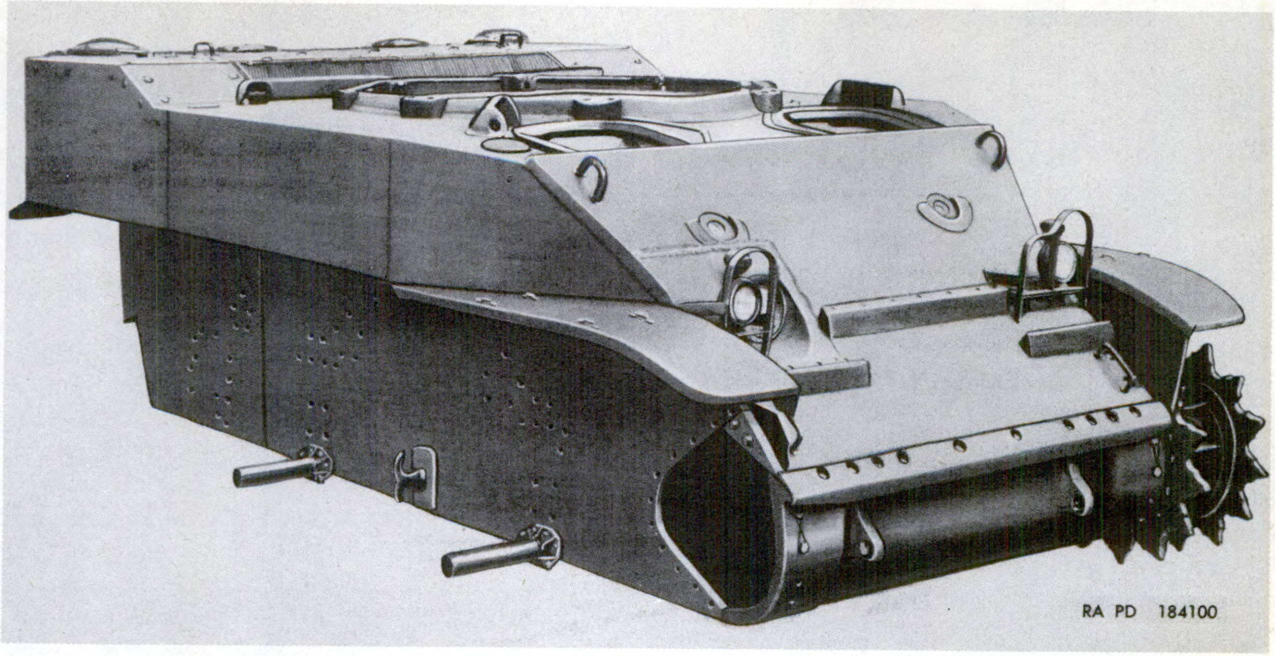


Figure 548. Tank hull.

to facilitate inspection and maintenance operations. On the amphibious version, bow and stern cells of reinforced and welded sheet steel are added to the basic hull in order to float the vehicle.

315. Hulls of Tracked Landing Vehicles

The hull of tracked landing vehicles is defined as the framework of the vehicle, together with all inside and outside plating but exclusive of equipment. It is the main, or central, section that runs from front to rear; it consists of the cab, cargo compartment, and engine room. Technically a part of the hull are the pontons which are welded to each side of it. Engines, controls, armament, and driving assemblies are housed in, or mounted on, the main hull.

316. Hulls of Amphibious Trucks

Amphibious trucks (fig. 575), unlike the two tracked vehicles mentioned in paragraph 315, have both a hull and a frame. Designed to provide buoyancy necessary for flotation, the basic hull assembly is of all-steel, watertight, welded construction, with reinforcements to add to its rigidity. It is built to accept the chassis frame and power plant. The frame, similar to a conventional truck frame, is installed inside and is bolted to the hull. The power plant and power train are supported by the frame; running gear, underneath the hull, is attached to both hull and frame.

CHAPTER 23

TURRET TRAVERSING AND GUN ELEVATING SYSTEMS

Section I. TURRET TRAVERSING SYSTEM

317. Description

(figs. 549 and 550)

The turret traversing system is provided to enable the turret to be traversed and trained quickly and accurately with a minimum of effort. An electric motor drives a 2-way, variable-displacement hydraulic pump which, in turn, supplies fluid power to a constant-displacement hydraulic motor. The pump is controlled by a control handle. An oil reservoir is provided to furnish oil to the pump and to receive the motor drainage. The turret can be traversed through any angle in either direction, at a variable speed.

318. Variable-Displacement Hydraulic Pump

(figs. 551 and 552)

The ported drive shaft, with its integral cylinder and rolling pistons, is driven by the electric motor. Centrifugal force, combined with the pressure in the hydraulic system, keeps the beveled surfaces of the rolling pistons against the inner race of the roller bearing at all times. Through contact of the rolling pistons, the roller bearing inner race rotates with the cylinder and the ported drive shaft. The slide-block race, which moves on two caged rollers between ground surfaces on the race and on plates in the pump case, is moved above or below the ported drive shaft center axis by operation of the hydraulically operated control cam, slide-block backup piston, and slide-block backup spring. Increasing the eccentricity of the slide-block race with respect to the drive shaft increases the stroke of the rolling pistons and the volume of oil discharged to the motor. Reversing the eccentricity of the slide-block race reverses the direction of oil flow. Oil flows to and from the

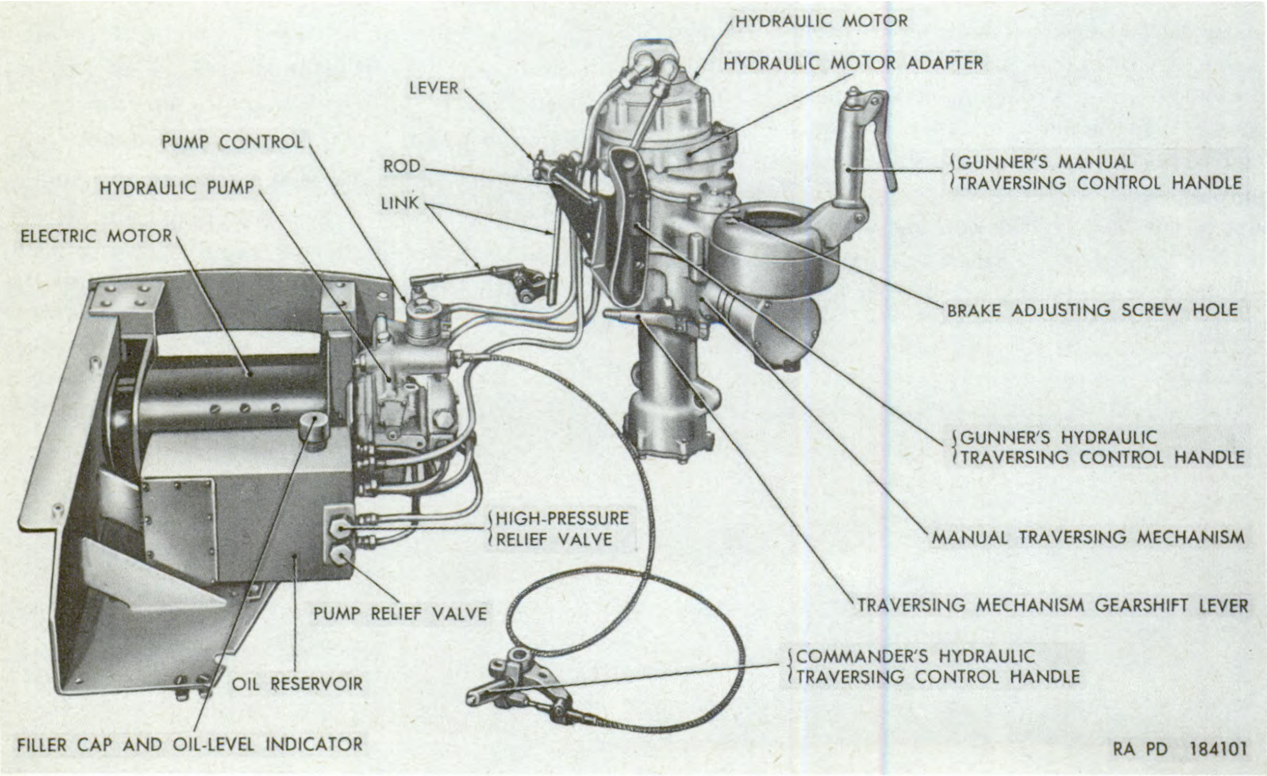

HYDRAULIC MOTOR
HYDRAULIC MOTOR ADAPTER
LEVER
PUMP CONTROL
ROD
HYDRAULIC PUMP
LINK
ELECTRIC MOTOR
GUNNER'S MANUAL TRAVERSING CONTROL HANDLE
BRAKE ADJUSTING SCREW HOLE
GUNNER'S HYDRAULIC TRAVERSING CONTROL HANDLE
HIGH-PRESSURE RELIEF VALVE
MANUAL TRAVERSING MECHANISM
PUMP RELIEF VALVE
TRAVERSING MECHANISM GEARSHIFT LEVER
COMMANDER'S HYDRAULIC TRAVERSING CONTROL HANDLE
OIL RESERVOIR
FILLER CAP AND OIL-LEVEL INDICATOR
RA PD 184101

Figure 549. Hydraulic turret traversing system.

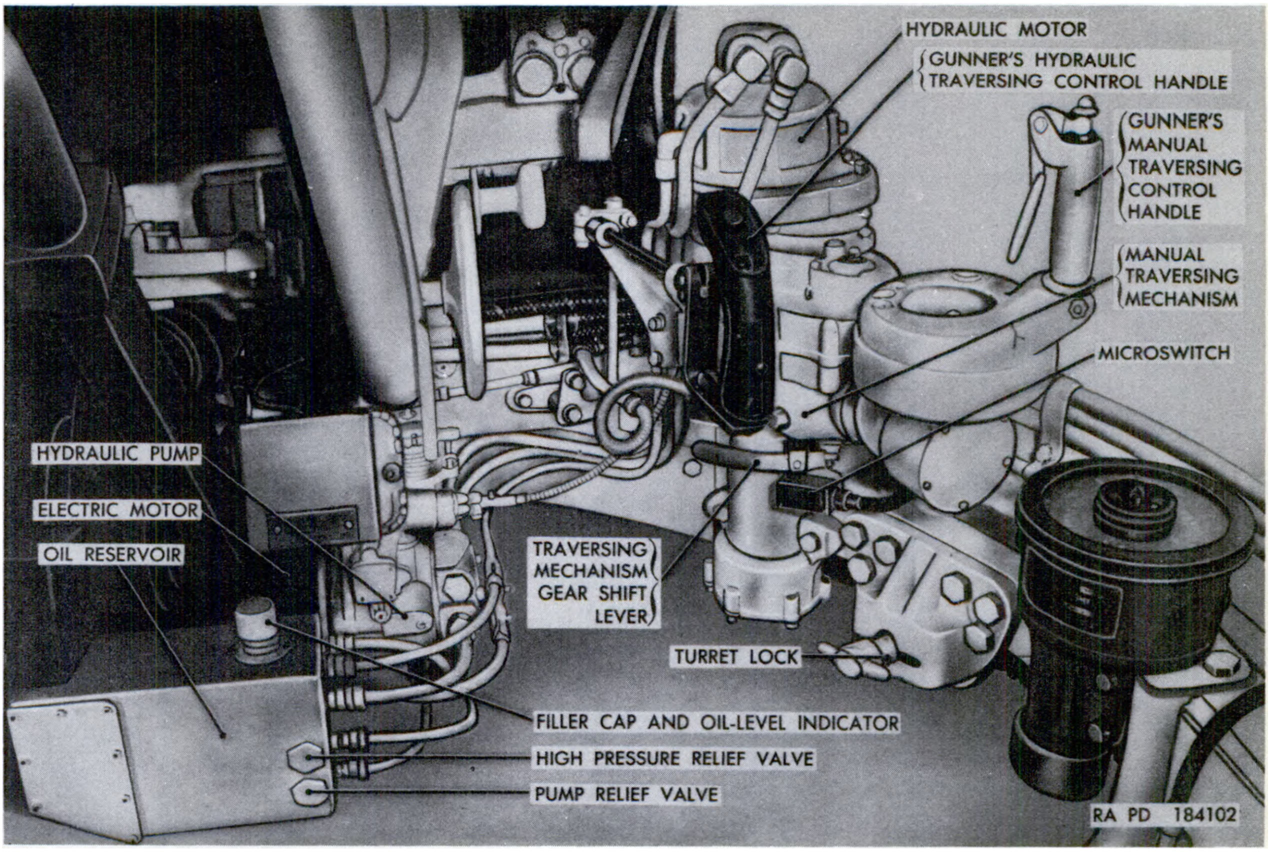

HYDRAULIC MOTOR
GUNNER'S HYDRAULIC TRAVERSING CONTROL HANDLE
GUNNER'S MANUAL TRAVERSING CONTROL HANDLE
MANUAL TRAVERSING MECHANISM
MICROSWITCH
HYDRAULIC PUMP
ELECTRIC MOTOR
OIL RESERVOIR
TRAVERSING MECHANISM GEAR SHIFT LEVER
TURRET LOCK
FILLER CAP AND OIL-LEVEL INDICATOR
HIGH PRESSURE RELIEF VALVE
PUMP RELIEF VALVE
RA PD 184102

Figure 550. Hydraulic turret traversing system installed in tank.

rolling pistons through machined passages in the pump and head, backup pistons, holddown tumblers, flat valve, drive shaft, and cylinder.

319. Constant-Displacement Hydraulic Motor
(figs. 553 and 554)

The constant-displacement hydraulic motor consists of a ported drive shaft with integral cylinder and rolling pistons, a roller bearing, and a flat valve with two crescent-shaped openings that direct the oil into and out of the motor. Direction of rotation of the motor depends on whether the upper or lower crescent of the flat valve receives the oil under pressure from the variable-displacement hydraulic pump. Centrifugal force and hydraulic pressure keep the beveled surfaces of the rolling pistons against the inner race of the roller bearing at all times. The outer roller bearing race is fitted in the motor case at a fixed eccentricity to the center axis of the drive shaft to provide piston stroke. The inner roller bearing race rotates with the cylinder and drive shaft through contact of the rolling pistons. When oil under pressure is received from the variable-displacement pump, the oil flows through one of the crescents in the flat valve to the ports in the drive shaft connected to that crescent. The rolling pistons, actuated through those ports, are forced outward, causing the roller bearing inner race and drive shaft to rotate. Delivery of oil through the second crescent causes rotation in the opposite direction. The speed of rotation depends upon the vol-

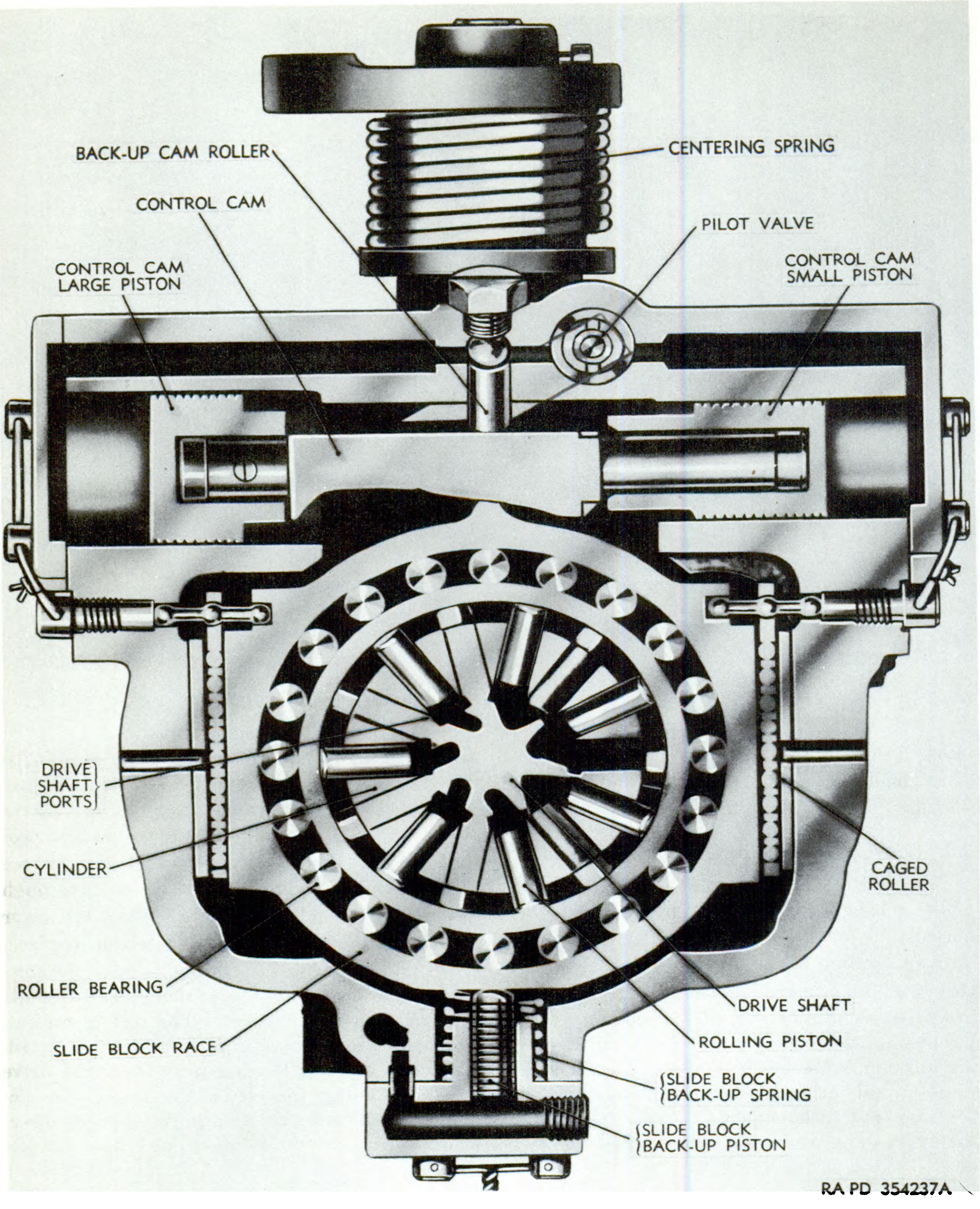

BACK-UP CAM ROLLER
CENTERING SPRING
CONTROL CAM
PILOT VALVE
CONTROL CAM LARGE PISTON
CONTROL CAM SMALL PISTON
DRIVE SHAFT PORTS
CYLINDER
CAGED ROLLER
ROLLER BEARING
DRIVE SHAFT
SLIDE BLOCK RACE
ROLLING PISTON
SLIDE BLOCK BACK-UP SPRING
SLIDE BLOCK BACK-UP PISTON
RA PD 354237A

Figure 551. Variable-displacement hydraulic pump—transverse cross sectional view.

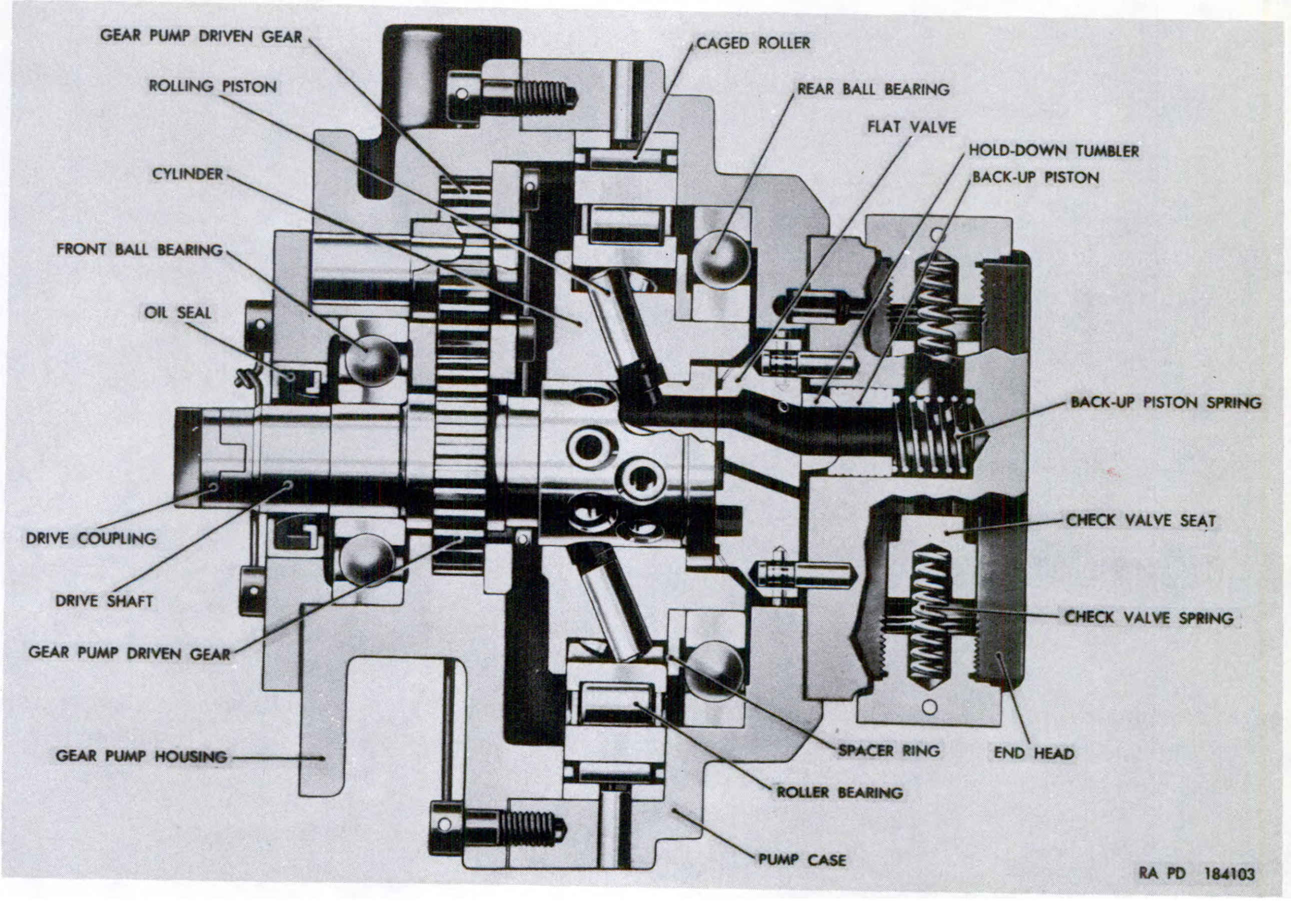

GEAR PUMP DRIVEN GEAR
ROLLING PISTON
CYLINDER
FRONT BALL BEARING
OIL SEAL
DRIVE COUPLING
DRIVE SHAFT
GEAR PUMP DRIVEN GEAR
GEAR PUMP HOUSING
CAGED ROLLER
REAR BALL BEARING
FLAT VALVE
HOLD-DOWN TUMBLER
BACK-UP PISTON
BACK-UP PISTON SPRING
CHECK VALVE SEAT
CHECK VALVE SPRING
SPACER RING
END HEAD
ROLLER BEARING
PUMP CASE
RA PD 184103

Figure 552. Variable-displacement hydraulic pump—longitudinal cross sectional view.

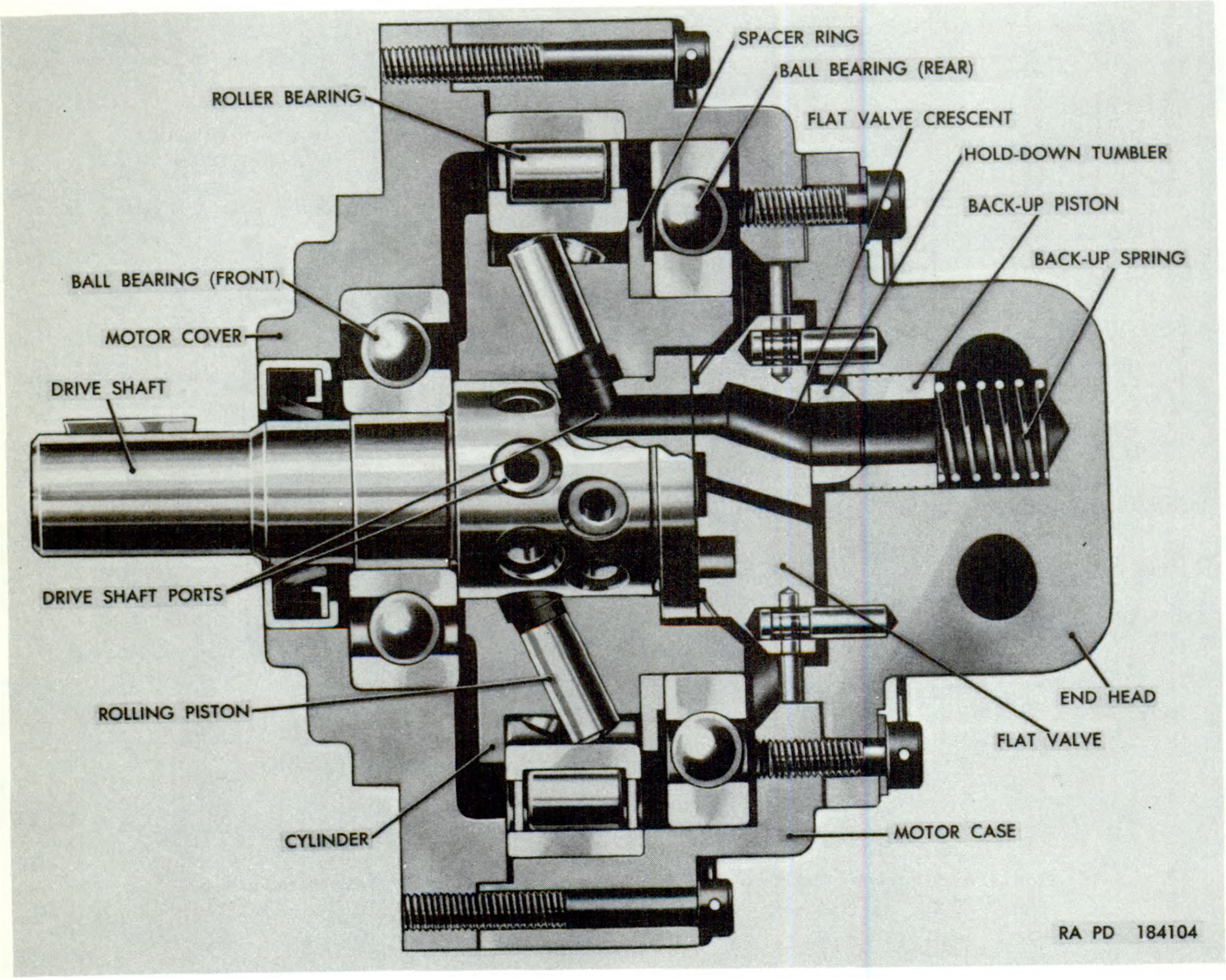

SPACER RING
BALL BEARING (REAR)
ROLLER BEARING
FLAT VALVE CRESCENT
HOLD-DOWN TUMBLER
BACK-UP PISTON
BACK-UP SPRING
BALL BEARING (FRONT)
MOTOR COVER
DRIVE SHAFT
DRIVE SHAFT PORTS
END HEAD
ROLLING PISTON
FLAT VALVE
CYLINDER
MOTOR CASE
RA PD 184104

Figure 553. ***Constant-displacement hydraulic motor—longitudinal cross sectional view.***

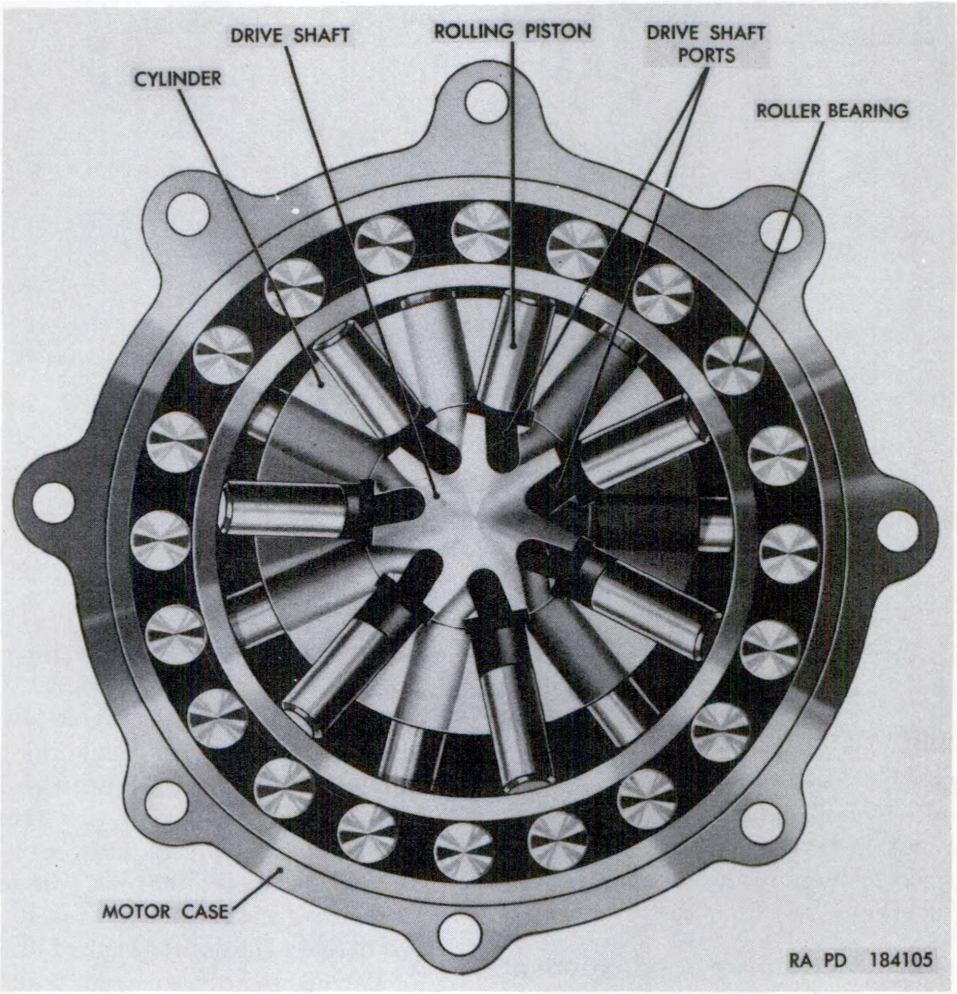

DRIVE SHAFT
ROLLING PISTON
DRIVE SHAFT PORTS
CYLINDER
ROLLER BEARING
MOTOR CASE
RA PD 184105

Figure 554. Constant-displacement hydraulic motor—transverse cross sectional view.

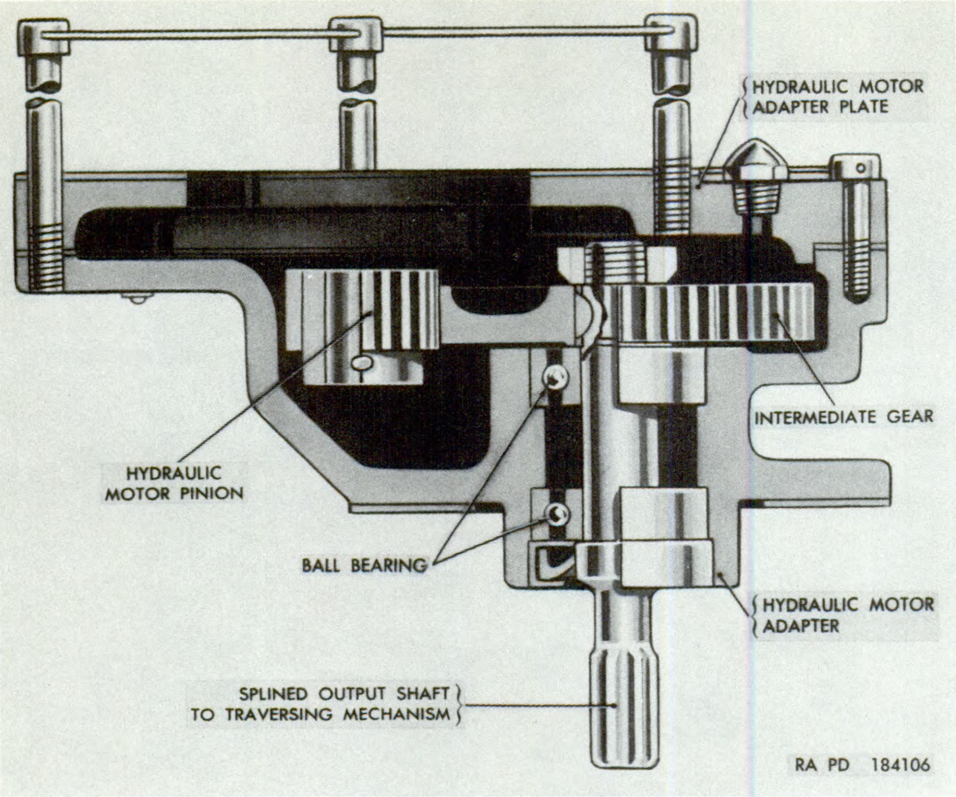

HYDRAULIC MOTOR ADAPTER PLATE
INTERMEDIATE GEAR
HYDRAULIC MOTOR PINION
BALL BEARING
HYDRAULIC MOTOR ADAPTER
SPLINED OUTPUT SHAFT TO TRAVERSING MECHANISM
RA PD 184106

Figure 555. Hydraulic motor adapter—cross sectional view.

ume of oil delivered by the variable-displacement hydraulic pump.

320. Hydraulic Motor Adapter

(fig. 555)

The hydraulic motor adapter, between the hydraulic motor and the traversing mechanism, is an intermediate gear reducer to increase torque and decrease output speed.

321. Traversing Mechanism and Manual Drive

(fig. 556)

a. Rotation of the turret is accomplished through gear trains that drive a pinion which is in mesh with a large, stationary, internal ring gear fastened to the hull of the tank. Operation of the mechanism causes the turret to rotate on ball bearings around the stationary ring gear. In hydraulic operation the gear train is driven by the hydraulic motor, through the hydraulic motor adapter and its splined shaft, and through two pairs of bevel gears and one pair of spur gears. A traversing mechanism gearshift lever is provided to select the desired type of drive.

b. The manual drive assembly includes a brake mechanism for locking the turret in position. The brake holding springs are released to traverse the turret by squeezing the brake release grip lever on the gunner's manual traversing control handle.

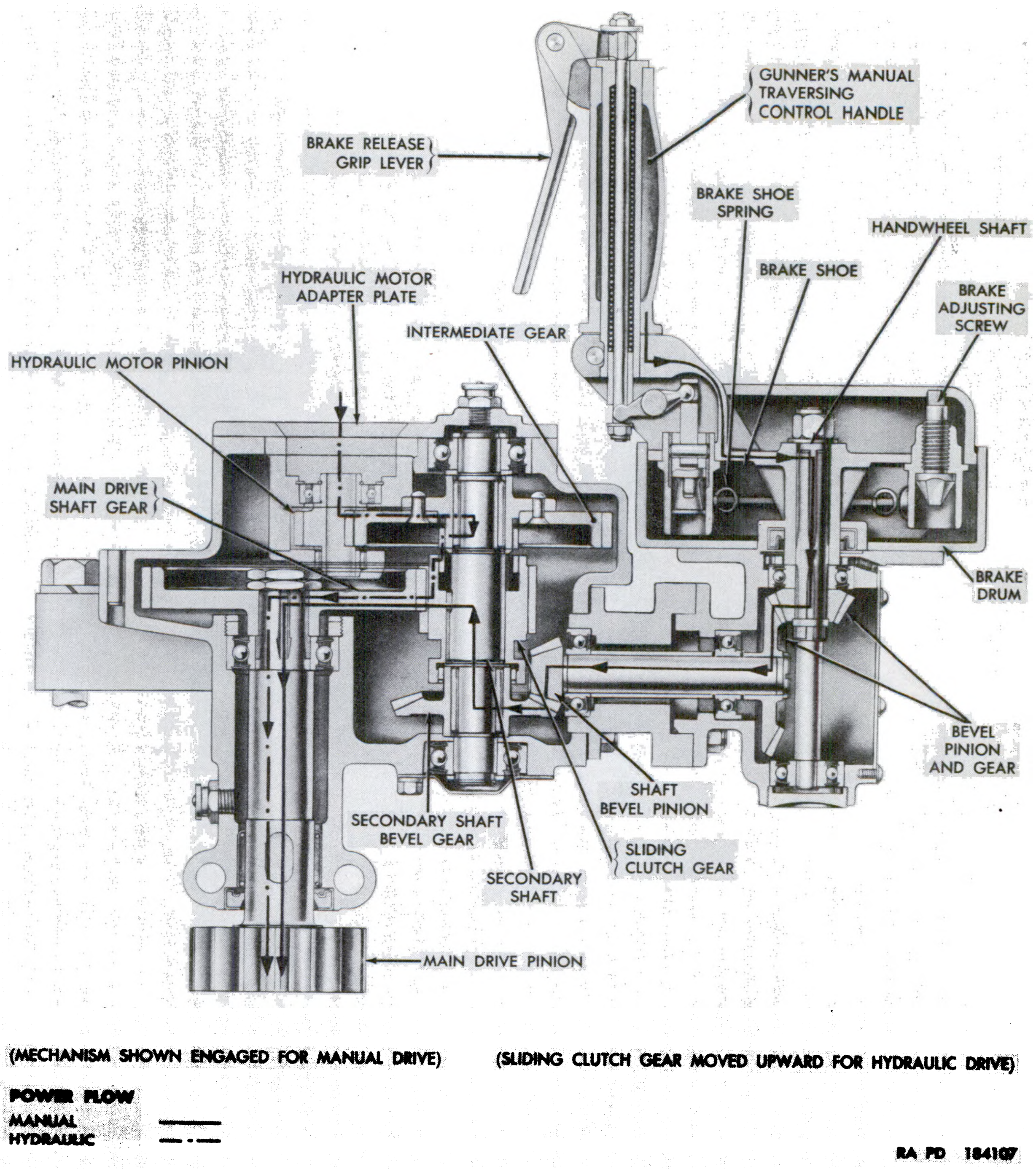
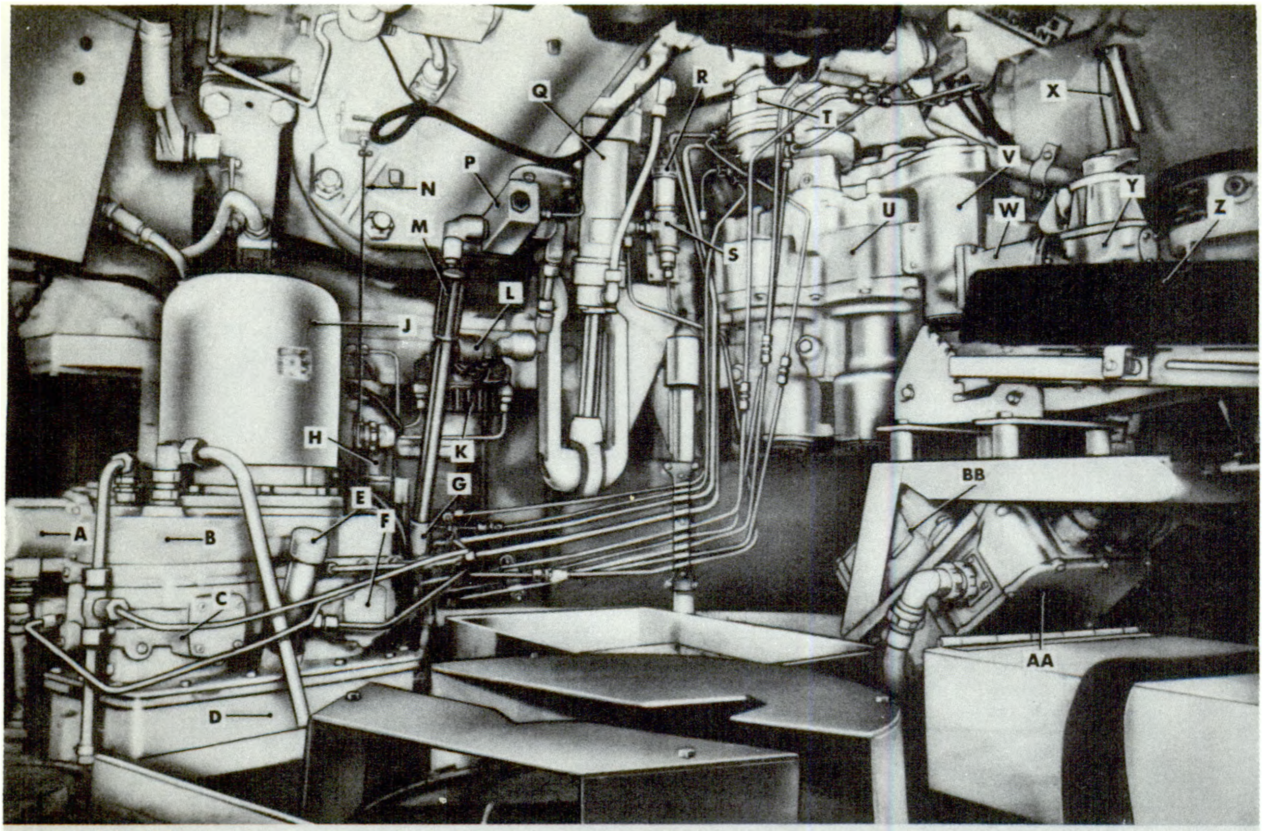

GUNNER'S MANUAL TRAVERSING CONTROL HANDLE
BRAKE RELEASE GRIP LEVER
BRAKE SHOE SPRING
HANDWHEEL SHAFT
BRAKE SHOE
BRAKE ADJUSTING SCREW
HYDRAULIC MOTOR ADAPTER PLATE
INTERMEDIATE GEAR
HYDRAULIC MOTOR PINION
MAIN DRIVE SHAFT GEAR
BRAKE DRUM
BEVEL PINION AND GEAR
SHAFT BEVEL PINION
SECONDARY SHAFT BEVEL GEAR
SLIDING CLUTCH GEAR
SECONDARY SHAFT
MAIN DRIVE PINION
(MECHANISM SHOWN ENGAGED FOR MANUAL DRIVE)
(SLIDING CLUTCH GEAR MOVED UPWARD FOR HYDRAULIC DRIVE)
POWER FLOW
MANUAL
HYDRAULIC
RA PD 184107

Figure 556. Traversing gear mechanism and manual drive—cross sectional view.



A—TURRET-TRAVERSING SIGNAL MOTOR
B—DRIVE GEAR CASE
C—TURRET-TRAVERSING HYDRAULIC PUMP
D—RESERVOIR
E—FILLER PIPE CAP
F—GUN-ELEVATING HYDRAULIC PUMP
G—HAND-OPERATED SUPERCHARGE PUMP
H—ACCUMULATOR
J—ELECTRIC DRIVE MOTOR
K—TURRET RING GEAR
L—HYDRAULIC SWIVEL JOINT
M—SUPERCHARGE PUMP HANDLE
N—ELEVATION FEED-BACK CABLE
P—HYDRAULIC-SWIVEL-JOINT MANIFOLD
Q—ELEVATING CYLINDER
R—PUMP-VALVE SOLENOID
S—DUMP VALVE
T—TURRET-TRAVERSING HYDRAULIC MOTOR
U—TRAVERSING MECHANISM
V—SLIP CLUTCH
W—NO-BACK DEVICE
X—TRAVERSE CRANK HANDLE
Y—HAND DRIVE
Z—GUNNER'S SEAT
AA—OVERRIDE CONTROL BOX
BB—PULSING RELAY BOX

RA PD 184108

Figure 557. Turret traversing and gun elevating system components.

Section II. TURRET TRAVERSING AND GUN ELEVATING SYSTEM

322. Description

(figs. 557 and 558)

a. General. The turret traversing and gun elevating system consists of mechanical, electrical, and hydraulic components so arranged as to permit either the gunner or crew commander to traverse the turret and/or elevate or depress and fire the gun quickly and accurately with a minimum of effort. The commander's control has a switch which enables the commander to override the gunner's control. In addition, there is provision for mechanical operation of the turret traversing and gun elevating systems in case of power or other failure.

b. Components and Their Relationship (fig. 558).

(1) The components of the system consist of the following: commander's control handle and gunner's control handle which feed electrical signals into the override control box, the pulsing relay box which translates these signals electrically to provide proper operation of the signal motors, the traversing control system, and the gun elevating system. In the trav-

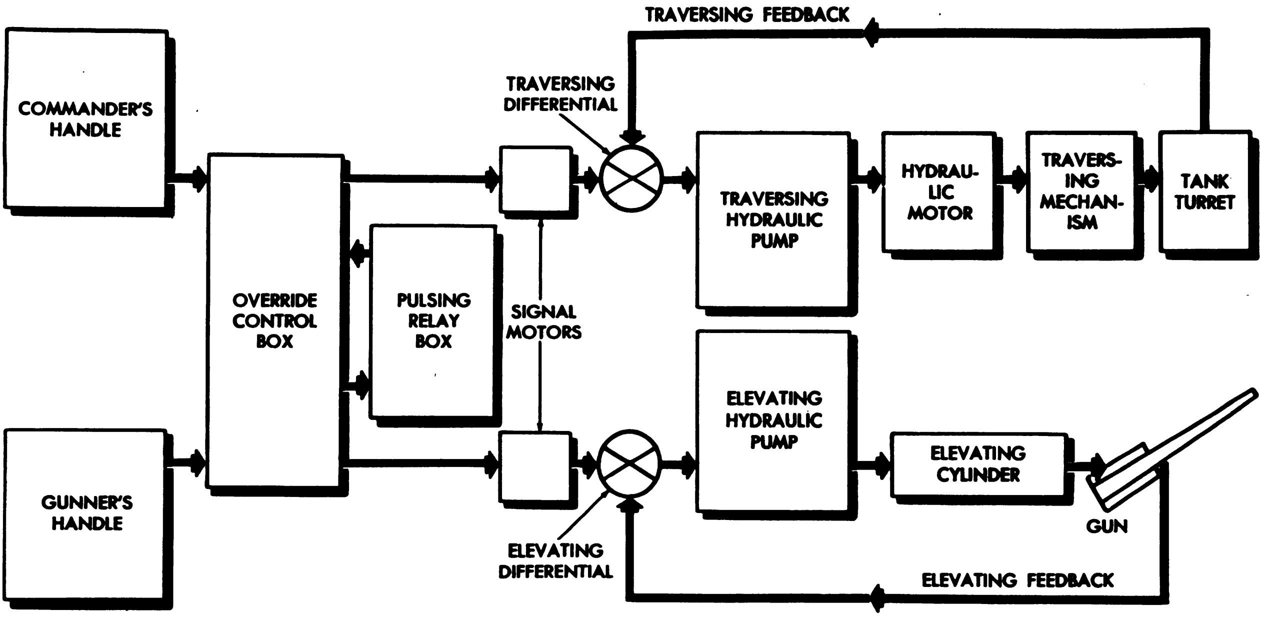

TRAVERSING FEEDBACK
TRAVERSING DIFFERENTIAL
COMMANDER'S HANDLE
OVERRIDE CONTROL BOX
PULSING RELAY BOX
SIGNAL MOTORS
TRAVERSING HYDRAULIC PUMP
HYDRAULIC MOTOR
TRAVERSING MECHANISM
TANK TURRET
ELEVATING HYDRAULIC PUMP
ELEVATING CYLINDER
GUN
GUNNER'S HANDLE
ELEVATING DIFFERENTIAL
ELEVATING FEEDBACK
RA PD 184109

Figure 558. Turret traversing and gun elevating system—schematic view.

ersing control system, the signal motor feeds varying rotary speeds into the traversing differential according to the electrical signals from the control box. The traversing differential, in effect a part of the traversing hydraulic pump, accepts this varying signal motor speed and combines it with rotary motion introduced into the traversing differential by a traversing feedback which is a gear train set into motion by the tank-turret motion. These two factors affect the traversing hydraulic pump, causing it to deliver more or less hydraulic fluid (oil) to the hydraulic motor. The hydraulic motor then drives the traversing mechanism faster or slower in accordance with the original signal from the control handle. The feedback provides quicker and more accurate control.

(2) The gun elevating system has a similar feedback from the gun, which feeds rotary motion into the elevating differential. This rotary motion is combined with the motion from the elevating signal motor to cause the elevating hydraulic pump to deliver hydraulic fluid (oil) to the elevating cylinder at varying speeds of delivery. The gun is thus elevated in accordance with the original signal from the control handle.

(3) Both systems are reversible. That is, the control handle can be manipulated so as to make the turret traverse in one direction or the other, and to make the gun elevate or depress.

323. Operation of Control System

a. Gunner's Control Handle (fig. 559). The gunner's control handle has pistol grips (left and right) that can be twisted about a vertical axis for turret traversing control, or shifted back or forward about a horizontal axis for gun elevating control. These two motions actuate electrical resistance devices in the control housing, that feed electrical signals of varying strength into the override control box. The amount and direction of pistol-grip motion determine the strength and direction of the electrical signals and, therefore, the direction and speed of turret traverse and gun elevation or depression.

b. Override Control Box. This is essentially a junction box with two electrical channels, one to the traversing control system and the other to the gun elevating control system. The control box also contains a relay that is energized by the commander's override switch to transfer control of traverse, elevating, and firing to the commander. Another relay starts and stops the electric drive

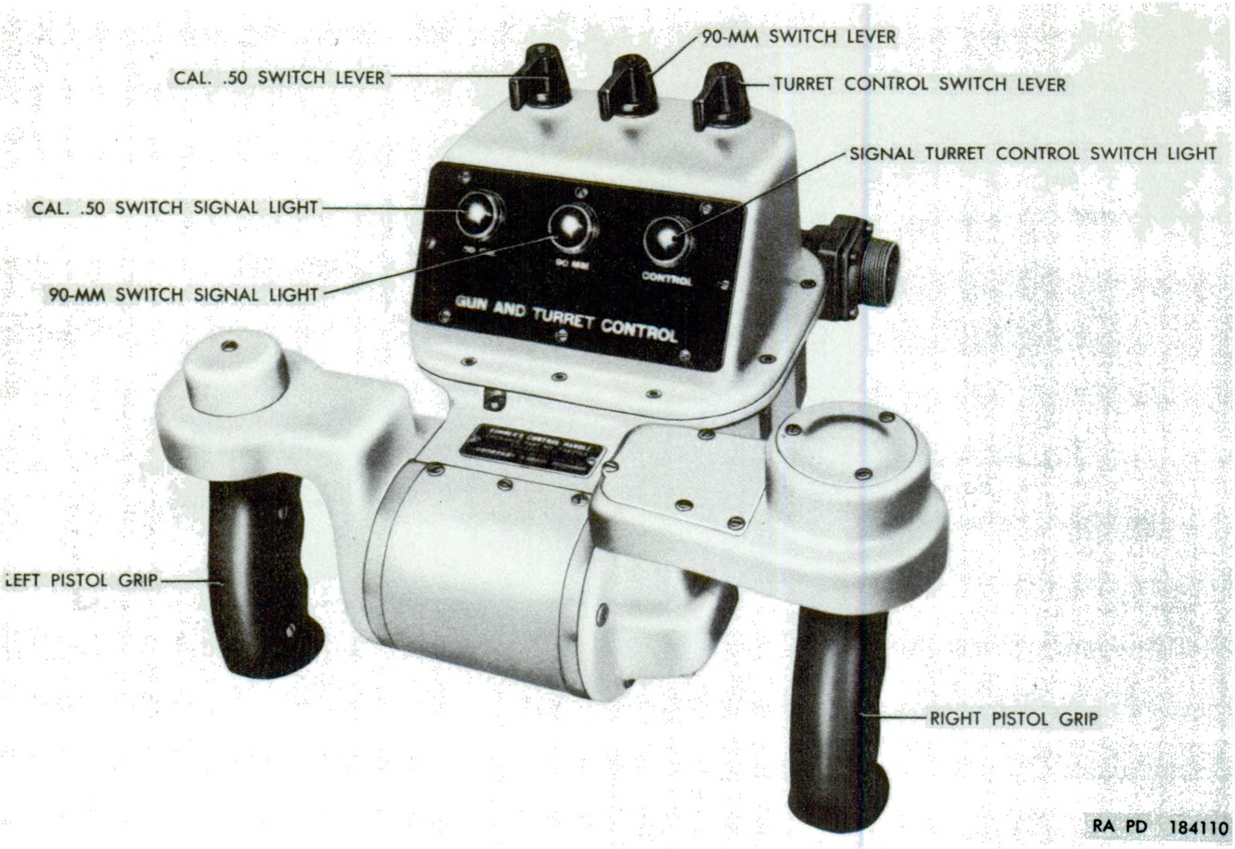

90-MM SWITCH LEVER
CAL. .50 SWITCH LEVER
TURRET CONTROL SWITCH LEVER
SIGNAL TURRET CONTROL SWITCH LIGHT
CAL. .50 SWITCH SIGNAL LIGHT
90-MM SWITCH SIGNAL LIGHT
GUN AND TURRET CONTROL
LEFT PISTOL GRIP
RIGHT PISTOL GRIP
RA PD 184110

Figure 559. Gunner's control handle.

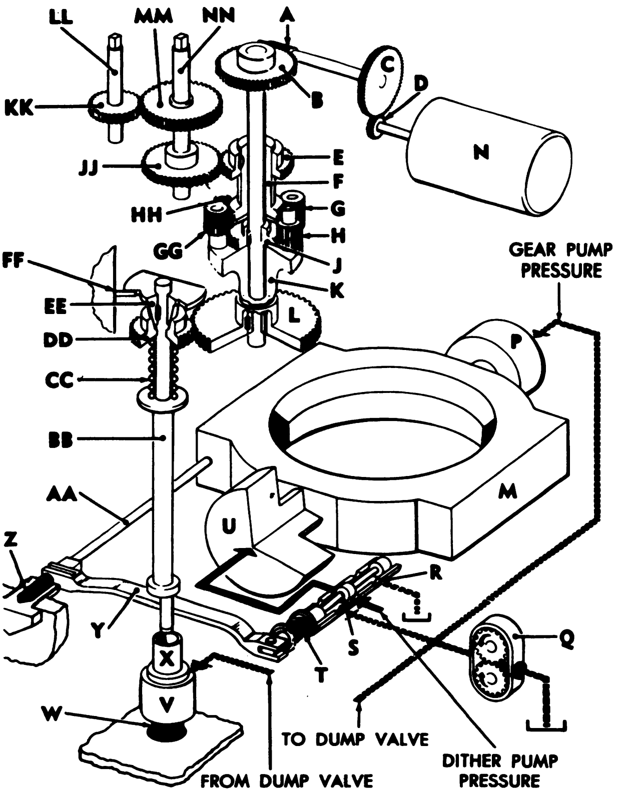
motor which, in turn, starts or stops the two hydraulic pumps. In addition, the control box contains circuit breakers to protect the system from electrical overload, and connections to gun elevating and depressing limit switches, as well as the traversing safety box. All these devices are safety or limit-protective devices.

c. Pulsing Relay Box. The pulsing relay box is essentially a wide-range speed control for the two signal motors, controlling the speed of each independently, in accordance with the position of the control handle. It also serves to maintain signal motor speed at the value selected under varying load conditions. In effect, the pulsing relay box serves as an intermediate agency to translate the basic signals from the control handle into electrical operating currents to the signal motors. Thus, the signal motor of the traversing system is driven slow or fast, in one direction or the other, to secure turret traverse in one direction or the other at varying speeds. And the signal motor of the gun elevating system is driven slow or fast, in one direction or the other, to secure gun elevation or depression at varying speeds.

d. Signal Motor. The signal motors of both systems are similar. The motor has two field windings; one field winding is energized for rotation in one direction, the other field winding is energized for rotation in the other direction. Thus, the motor armature can rotate in either direction and at varying speeds.

e. Signal Motor Control Action—Traversing System (fig. 560).

(1) Figure 560 is a schematic view of the gear train driven by the signal motor which carries the control signal to the hydraulic pump. Operation of the hydraulic pump is explained in paragraph 324. For the present, remember only that as the slide block (M) assembly is moved in one direction or the other, the hydraulic pump delivers hydraulic fluid, under pressure, in one direction or the other. This means that the hydraulic motor, which is driven by the pressure from the pump, would turn one way or the other, causing the turret to traverse in one direction or the other. Further, the amount



A—CONTROL WORM
B—DIFFERENTIAL INPUT GEAR
C—WORM SHAFT GEAR
D—SIGNAL MOTOR SHAFT GEAR
E—DIFFERENTIAL FEED-BACK INPUT GEAR
F—UPPER SUN GEAR
G—UPPER PLANETARY GEAR
H—LOWER PLANETARY GEAR
J—LOWER SUN GEAR
K—OUTPUT GEAR CARRIER
L—TRAVERSING DIFFERENTIAL OUTPUT GEAR
M—SLIDE BLOCK ASSEMBLY
N—SIGNAL MOTOR ASSEMBLY
P—SMALL CONTROL PISTON
Q—TRAVERSING PUMP DRIVE GEAR
R—PILOT VALVE BUSHING
S—PILOT VALVE PLUNGER
T—TRAVERSING PILOT VALVE PLUNGER SPRING
U—LARGE CONTROL PISTON
V—NEUTRAL LOCK CYLINDER
W—NEUTRAL LOCK SPRING
X—NEUTRAL LOCK PLUNGER
Y—CONTROL LEVER
Z—FOLLOW-UP PIN CAP
AA—FOLLOW-UP PIN
BB—TRAVERSING CONTROL ECCENTRIC SHAFT
CC—SLIP CLUTCH SPRING
DD—TRAVERSING CLUTCH GEAR
EE—CLUTCH LIMIT PLATE
FF—DOWEL PIN
GG—UPPER PLANETARY GEAR
HH—LOWER PLANETARY GEAR
JJ—LOWER FEEDBACK SHAFT GEAR
KK—AUXILIARY FEEDBACK GEAR
LL—AUXILIARY FEEDBACK SHAFT
MM—UPPER FEEDBACK SHAFT GEAR
NN—TRAVERSING FEEDBACK SHAFT

RA PD 184111

Figure 560. Turret traversing hydraulic pump control—schematic view.

of slide-block movement from a central position determines the amount of fluid delivered and the speed of traverse. With this fact in mind, study the gear train that controls the slide-block position.

(2) The signal motor assembly (N) drives the differential input gear (B) through gears and a control worm (C). Both the input gear (B) and the lower sun gear (J) are splined to the shaft so the lower sun gear turns with the input gear. This drives the lower planetary gears (H and HH). These gears drive the upper planetary gears (G and GG). When the differential feedback input gear (E) is stationary, the planetary gears walk around the upper sun gear (F), which is a part of the differential input gear (E). This carries the output gear carrier (K) around to turn the traversing differential output gear (L). The traversing differential gear drives the traversing control eccentric shaft (BB) through traversing clutch gear (DD) and clutch. A dowel pin (FF) and clutch limit plate (EE) limit the rotation in either direction and cause the clutch to slip after the eccentric pin in the eccentric shaft (BB) has reached either limiting position. The pin is the pivoting point for the control lever (Y). Moving the pin one way or the other changes the pivoting point, causing the control lever to move and moving the pilot valve plunger (S) in the pilot valve. This action alters the flow pattern of hydraulic fluid from the traversing pump drive gear (Q) to the control pistons (P and U). As a result, the control pistons move and change the position of the slide block assembly (M). Changing slide-block position produces turret traverse.

(3) When the turret begins to traverse, the auxiliary feedback gear (KK) is driven through auxiliary feedback shaft (LL), gears, shafts, and universal joints from the turret ring gear. The rotary motion of the gear (KK) is carried through the lower and upper feedback shaft gears (JJ

and MM) to the differential feedback input gear (E). The differential feedback input gear therefore rotates the upper sun gear (F). With the upper sun gear rotating, rotation of the output gear carrier (K) is slowed or halted. For example, suppose that a slow traverse of the turret is demanded by a small movement of the control handle. The signal motor will run slowly and this means that lower sun gear (J) will turn slowly. Also, the differential feedback input gear (E) and upper sun gear (F) will turn slowly. As a result, the traversing differential output gear (L) will turn only a small amount to turn the traversing control eccentric shaft (BB) only a small amount. This, in turn, means that the eccentric pin in the lower end of the eccentric shaft (BB) will move only a little way from the neutral position. This action moves the control lever (Y) only a little from the neutral position, causing only a small movement of the slide block assembly (M). As a result, the turret traverses slowly. If, on the other hand, rapid traversing is desired, the signal motor speed is increased (by control handle movement). This increased speed is reflected by a further rotation of the differential output gear (L) which turns the control eccentric shaft (BB) further so as to produce, through the control lever (Y), a greater shift in the position of the slide block assembly (M).

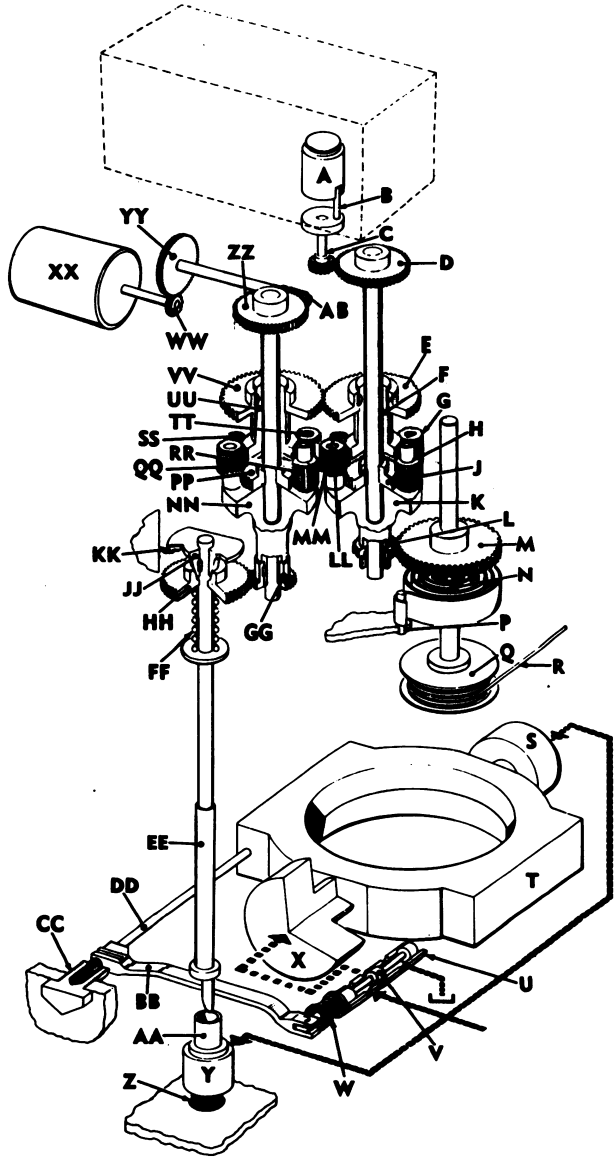
(4) The feedback principle makes possible greater accuracy in turret control. The movement of the turret as it traverses is reflected back to the control system through the feedback. The final control results from a combination of two signals, the original signal from the signal motor, and the signal through the feedback produced by turret traverse.

f. Signal-Motor Control Action—Gun-Elevating System (fig. 561).

(1) Figure 561 is a schematic view of the gear trains involved in the gun-elevating control system. Operation of the hydraulic pump is explained in paragraph 324. For the present, remember only that as the slide block assembly moves in one direction or the other, the hydraulic pump delivers hydraulic fluid, under pressure, in one direction or the other. This directs hydraulic fluid into one or another section of the gun elevating cylinder, thus elevating or depressing the gun. The hydraulic pump and gun elevating cylinder are discussed in paragraph 324.

(2) The signal motor assembly (XX) drives the differential input gear (ZZ) through gears and a control worm (AB). (This drive is carried through the planetary in exactly the same manner as in the turret traversing system (*e*(2) above). That is, the power flow is from the differential input gear (ZZ) through the lower sun gear (PP), lower planetary gears (RR and SS), and upper planetary gears (QQ and TT), causing the output gear carrier (NN) to rotate when the differential feedback input gear (VV) is stationary. This action carrys the eccentric pin on the elevating eccentric shaft (EE) around so the control lever (BB) is moved, causing the pilot valve plunger (V) to move. This action alters the flow pattern of the hydraulic fluid to the control pistons (S and X) so the slide block assembly (T) is moved. It is this slide-block movement that changes the pattern of hydraulic fluid flow to the gun elevating cylinder to produce gun elevation or depression.

(3) When the gun begins to elevate or depress, the feedback comes into operation through the second planetary system. The feedback is a system that reflects gun movement through the planetary gear systems thereby, introducing rotary motion to the differential feedback input gear (VV). The feedback operates through the feedback cable (R), which is fastened to the breechblock end of the gun. As the gun elevates or depresses, the cable either winds up or unwinds on pulley assembly (Q). This rotates feedback shaft gear (M) and introduces rotary motion into the right planetary. If the lower sun gear (J) in this planetary is held stationary, the rotary motion will be carried through the planetary and to



A —ACTUATOR DUMMY PLUG
B —SUPERELEVATING COUPLING PIN
C —SUPERELEVATING INPUT GEAR
D —SUPERELEVATING DIFFERENTIAL INPUT GEAR
E —DIFFERENTIAL FEEDBACK INPUT GEAR
F —UPPER SUN GEAR
G —UPPER PLANETARY GEAR
H —LOWER PLANETARY GEAR
J —LOWER SUN GEAR
K —OUTPUT GEAR CARRIER
L —DIFFERENTIAL OUTPUT ELEVATING GEAR
M —FEEDBACK SHAFT GEAR
N —FEEDBACK SHAFT SPRING
P —LOWER ELEVATION CONTROL CASE
Q —PULLEY ASSEMBLY
R —FEEDBACK CABLE
S —SMALL CONTROL PISTON
T —SLIDE BLOCK ASSEMBLY
U —PILOT VALVE BUSHING
V —PILOT VALVE PLUNGER
W —ELEVATING PILOT VALVE PLUNGER SPRING
X —LARGE CONTROL PISTON
Y —NEUTRAL LOCK CYLINDER
Z —NEUTRAL LOCK SPRING
AA —NEUTRAL LOCK PLUNGER
BB —CONTROL LEVER
CC —FOLLOW-UP LEVER CAP
DD —FOLLOW-UP PIN
EE —ELEVATING ECCENTRIC SHAFT
FF —SLIP CLUTCH SPRING
GG —ELEVATING DIFFERENTIAL OUTPUT GEAR
HH —ELEVATING CLUTCH GEAR
JJ —CLUTCH LIMIT PLATE
KK —DOWEL PIN
LL —UPPER PLANETARY GEAR
MM —LOWER PLANETARY GEAR
NN —OUTPUT GEAR CARRIER
PP —LOWER SUN GEAR
QQ —UPPER PLANETARY GEAR
RR —LOWER PLANETARY GEAR
SS —LOWER PLANETARY GEAR
TT —UPPER PLANETARY GEAR
UU —UPPER SUN GEAR
VV —DIFFERENTIAL FEEDBACK INPUT GEAR
WW—SIGNAL MOTOR SHAFT GEAR
XX —SIGNAL MOTOR ASSEMBLY
YY —WORM SHAFT GEAR
ZZ —DIFFERENTIAL INPUT GEAR
AB —CONTROL WORM

RA PD 184112

Figure 561. Gun elevating hydraulic pump control—schematic view.

the differential feedback input gear (E). This motion causes the differential feedback input gear (VV) on the outer planetary to rotate. This rotates the upper sun gear (UU) so that rotation of the output gear carrier (NN) is slowed or halted. For example, suppose that a slow elevation of the gun is demanded by a small movement of the control handle. The signal motor will run slowly; this means that the lower sun gear (PP) will turn slowly. Also, the gun will elevate slowly, causing the differential feedback input gear (VV) to rotate slowly due to the motion introduced through the other planetary by the feedback mechanism. As a consequence of introducing these two motions, the elevating differential output gear (GG) turns only a small amount, thus turning the elevating eccentric shaft (EE) only a small amount. Since the elevating eccentric shaft (EE) turns only a small amount, the eccentric pin in its end is displaced from neutral only a little, resulting in only a small movement of the control lever (BB). This means that the hydraulic fluid moves slowly from the hydraulic pump to the elevating cylinder, causing a slow elevation of the gun.

(4) The feedback principle makes possible quicker and more accurate aiming. The actual movement of the gun itself, as it is elevated or depressed, is reflected back to the control system through the feedback. The actual control therefore results from a combination of two signals, the original signal from the signal motor and the signal through the feedback from the moving gun.

(5) The superelevating device (operating from range finder) can take over and control gun elevation, superseding during that time the signal motor. That is, the signal motor stops, thus, stopping the lower sun gear (PP) in the left planetary. The superelevating device drives the coupling pin (B) and, through the gear train, the lower sun gear (J). This action causes the lower and upper planetary gears (H, MM, G, and LL) to rotate, and causes rotation of the upper sun gear and differential feedback input gear (E) (when the differential output elevating gear (L) is stationary). Rotation is now carried through the other planetary and thence to the elevating eccentric shaft (EE), causing the eccentric pin to move the control lever (BB) to produce gun movement as explained in (3) above. As the gun begins to move, the feedback system comes into operation (through the feedback cable (R), pulley assembly (Q), and gears (M and L)). The two motions (from superelevating device and from feedback) combine to produce the amount of elevating eccentric shaft (EE) rotation and control lever (BB) movement called for by the superelevating device to secure the selected speed of gun movement.

324. Operation of Hydraulic System

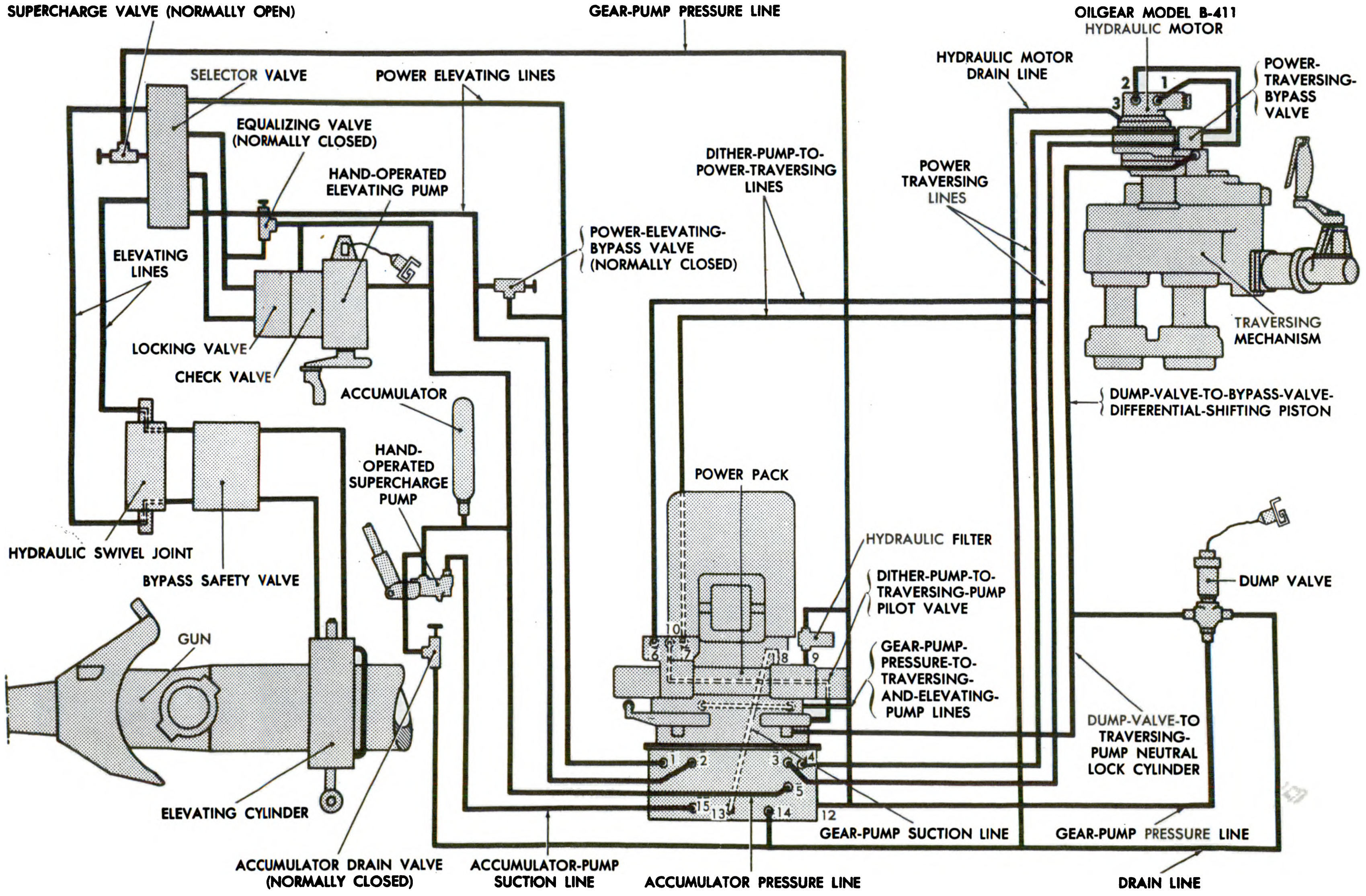
a. General. As mentioned in paragraph 323, the control system, which includes the mechanism from the control handle (gunner's or commander's) to the control lever in the hydraulic pump, exercises control by shifting the slide-block assembly in the pump. As the slide block is moved to one side or the other, the pump delivers hydraulic fluid in one direction or the other. The greater the slide-block movement, the greater the amount of fluid delivered. In the turret traversing system, the fluid is delivered to a hydraulic motor. When the fluid is delivered in one direction, the hydraulic motor drive shaft rotates in one direction. Reversing the fluid flow reverses rotation. Also, the greater the amount of fluid delivered, the faster the motor drive shaft rotates. Thus, the turret can be made to traverse in one direction or the other and at varying speeds. In the gun elevating system, the hydraulic pump delivers hydraulic fluid to one or the other end of a double-ram gun elevating cylinder. When the fluid enters one end, the gun is elevated. When it enters the other end, the gun is depressed. The rate of fluid delivery, which is determined by the amount of slide-block movement, governs the speed of gun movement. There are separate hydraulic pumps for the turret traversing system and the gun elevating system. However, both are constructed and operate in a very similar manner.

b. Hydraulic System. The complete hydraulic system for both turret traverse and gun elevation is shown schematically in figure 562. Both hydraulic pumps, along with the electric motor to drive them, are enclosed in the powerpack. The powerpack also contains a gear pump for producing an initial pressure in the hydraulic fluid, as well as a dither pump for producing pulsating pressure in the hydraulic lines (for a purpose to be explained in (6) below). There is an oil (hydraulic fluid) reservoir in the base of the powerpack, and hydraulic lines connect between the powerpack and the various valves and hydraulic motor which comprise the hydraulic system.

c. Turret Traverse Hydraulic System.

(1) The turret traverse hydraulic system is shown schematically in figure 563. It consists essentially of the following parts: hydraulic pump driven by the electric motor in the power pack; gear pump driven by same motor; dither pump driven by same motor; hydraulic motor driven by oil from hydraulic pump; various control valves; and hydraulic lines connecting the components.

(2) The hydraulic pump, very similar in action to the one described in paragraph 318, produces its pumping action by means of a series of pistons set in holes in the drive shaft. When the pump slide-


SUPERCHARGE VALVE (NORMALLY OPEN)
GEAR-PUMP PRESSURE LINE
OILGEAR MODEL B-411 HYDRAULIC MOTOR
HYDRAULIC MOTOR DRAIN LINE
POWER-TRAVERSING-BYPASS VALVE
SELECTOR VALVE
POWER ELEVATING LINES
EQUALIZING VALVE (NORMALLY CLOSED)
HAND-OPERATED ELEVATING PUMP
DITHER-PUMP-TO-POWER-TRAVERSING LINES
POWER TRAVERSING LINES
POWER-ELEVATING-BYPASS VALVE (NORMALLY CLOSED)
ELEVATING LINES
LOCKING VALVE
CHECK VALVE
TRAVERSING MECHANISM
ACCUMULATOR
DUMP-VALVE-TO-BYPASS-VALVE-DIFFERENTIAL-SHIFTING PISTON
HAND-OPERATED SUPERCHARGE PUMP
POWER PACK
HYDRAULIC SWIVEL JOINT
BYPASS SAFETY VALVE
HYDRAULIC FILTER
DITHER-PUMP-TO-TRAVERSING-PUMP PILOT VALVE
DUMP VALVE
GUN
GEAR-PUMP-PRESSURE-TO-TRAVERSING-AND-ELEVATING-PUMP LINES
DUMP-VALVE-TO TRAVERSING-PUMP NEUTRAL LOCK CYLINDER
ELEVATING CYLINDER
GEAR-PUMP SUCTION LINE
GEAR-PUMP PRESSURE LINE
ACCUMULATOR DRAIN VALVE (NORMALLY CLOSED)
ACCUMULATOR-PUMP SUCTION LINE
ACCUMULATOR PRESSURE LINE
DRAIN LINE
1
2
3
4
5
6
7
8
9
10
12
13
14
15

RA PD 184113

Figure 562. Hydraulic system for operation of turret traversing and gun elevating systems—schematic view.

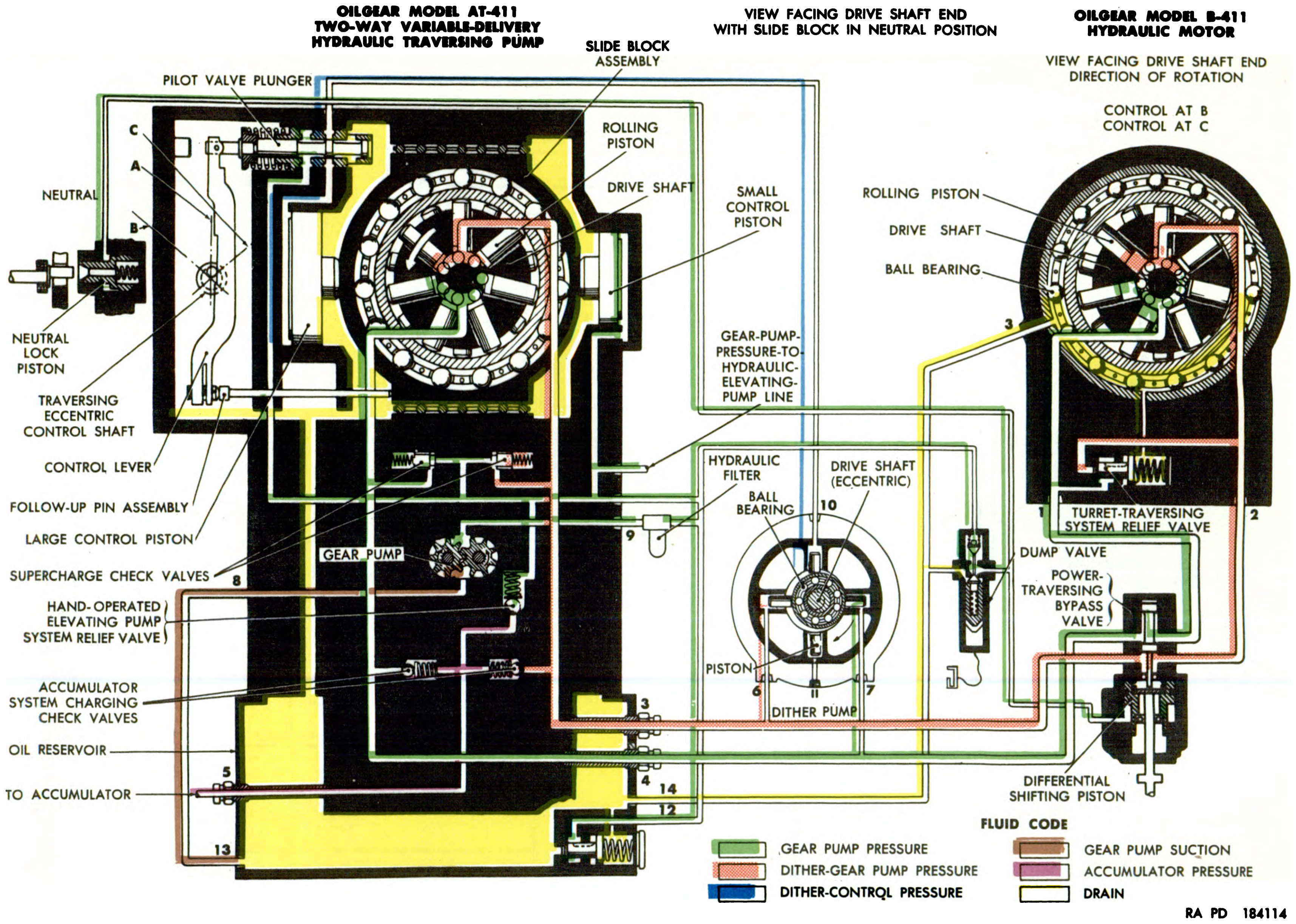

OILGEAR MODEL AT-411
TWO-WAY VARIABLE-DELIVERY
HYDRAULIC TRAVERSING PUMP
VIEW FACING DRIVE SHAFT END
WITH SLIDE BLOCK IN NEUTRAL POSITION
OILGEAR MODEL B-411
HYDRAULIC MOTOR
VIEW FACING DRIVE SHAFT END
DIRECTION OF ROTATION
CONTROL AT B
CONTROL AT C
SLIDE BLOCK ASSEMBLY
PILOT VALVE PLUNGER
ROLLING PISTON
DRIVE SHAFT
SMALL CONTROL PISTON
C
A
B
NEUTRAL
NEUTRAL LOCK PISTON
TRAVERSING ECCENTRIC CONTROL SHAFT
CONTROL LEVER
FOLLOW-UP PIN ASSEMBLY
LARGE CONTROL PISTON
SUPERCHARGE CHECK VALVES
GEAR PUMP
HAND-OPERATED ELEVATING PUMP SYSTEM RELIEF VALVE
ACCUMULATOR SYSTEM CHARGING CHECK VALVES
OIL RESERVOIR
TO ACCUMULATOR
GEAR-PUMP-PRESSURE-TO-HYDRAULIC-ELEVATING-PUMP LINE
HYDRAULIC FILTER
BALL BEARING
DRIVE SHAFT (ECCENTRIC)
PISTON
DITHER PUMP
ROLLING PISTON
DRIVE SHAFT
BALL BEARING
TURRET-TRAVERSING SYSTEM RELIEF VALVE
DUMP VALVE
POWER-TRAVERSING BYPASS VALVE
DIFFERENTIAL SHIFTING PISTON
1
2
3
3
4
5
6
7
8
9
10
11
12
13
14
FLUID CODE
GEAR PUMP PRESSURE
DITHER-GEAR PUMP PRESSURE
DITHER-CONTROL PRESSURE
GEAR PUMP SUCTION
ACCUMULATOR PRESSURE
DRAIN
RA PD 184114

Figure 563. Turret traverse hydraulic system—schematic view.

block assembly is centered, no pumping action takes place. However, if the slide block is moved to one side or the other, the pistons move in and out in the drive shaft holes. They are impelled to move in this way because the ball bearing inner race is no longer centered with the drive shaft; it is to one side as shown in figure 564. With each drive shaft revolution, and thus each piston stroke, oil is pumped into one of the hydraulic lines going to the hydraulic motor. The more the slide block is moved from the central position, the longer the piston strokes and the greater the amount of oil pumped. If the slide block is moved to the other side, oil will be pumped in the other direction through the pump, thereby causing the hydraulic motor to run in the opposite direction.

(3) Control of the hydraulic pump has been described in paragraph 323. As the control is operated, the traversing eccentric control shaft turns, forcing the eccentric pin in the shaft end to swing around in an arc. This moves the pin from neutral toward either position B or C, according to whether the control has called for clockwise or counterclockwise rotation of the hydraulic motor. If it has called for clockwise rotation, the conditions shown in figure 564 will result. Here, movement of the control lever from neutral to the position permitted by movement of the eccentric pin to "B" has taken place. This causes the pilot valve plunger (fig. 564) to move to the left, opening the passage between the oil reservoir and the large control piston cylinder. The oil back of the piston runs out and oil pressure behind the small control piston shifts the slide-block assembly to the left as shown. If the control calls for counterclockwise rotation of the hydraulic motor, the eccentric pin would be moved to position C. The control lever (fig. 564) would be moved to the right, introducing oil pressure from the gear pump in back of the large control piston. This pressure would move the slide-block assembly to the right; oil flow through the pump would be reversed (from what it was with pin in position B), and the hydraulic motor would run in the reverse direction.

(4) The amount of slide-block movement ((2) above), which is determined by the control system governing the position of the control lever, determines the amount of oil pumped to the hydraulic motor and, therefore, the speed of the hydraulic motor. Thus, turret traverse may be at varying speed, depending on the position of the slide block in the hydraulic pump.

(5) The hydraulic motor is, in effect, a hydraulic pump in reverse. A series of pistons is set in holes in the motor drive shaft. The drive shaft is permanently offcenter from the motor body and inner ball bearing race. Oil pressure from the hydraulic pump forces the pistons outward and imparts rotary motion to the drive shaft. If the oil pressure is applied through the lower hydraulic line (from connection 1 in motor body in fig. 564), the drive shaft will rotate clockwise as shown by the arrow. But if the oil pressure is applied through the upper hydraulic line from connection 2, the drive shaft will rotate counterclockwise.

(6) The dither pump contains four small pistons that ride in holes and bear against a ball bearing set on an eccentric drive shaft. When the drive shaft rotates, the pistons move back and forth, thereby applying pulsations of pressure in the hydraulic lines. The purpose of this is to prevent "hanging up" of any hydraulic parts. In effect, various moving parts in the hydraulic system are continually jarred by the pulsations so that they will respond quickly to changing signals from the control system. As a consequence, rapid and accurate operation of the turret traversing and gun elevating systems is achieved. Even very small adjustments in turret position can be obtained with accuracy because of the dither pump action.

(7) The dump valve comes into action when the turret is traversed mechanically by means of the traversing crank handle (par. 325). In case of power failure, the traversing crank handle can be used to

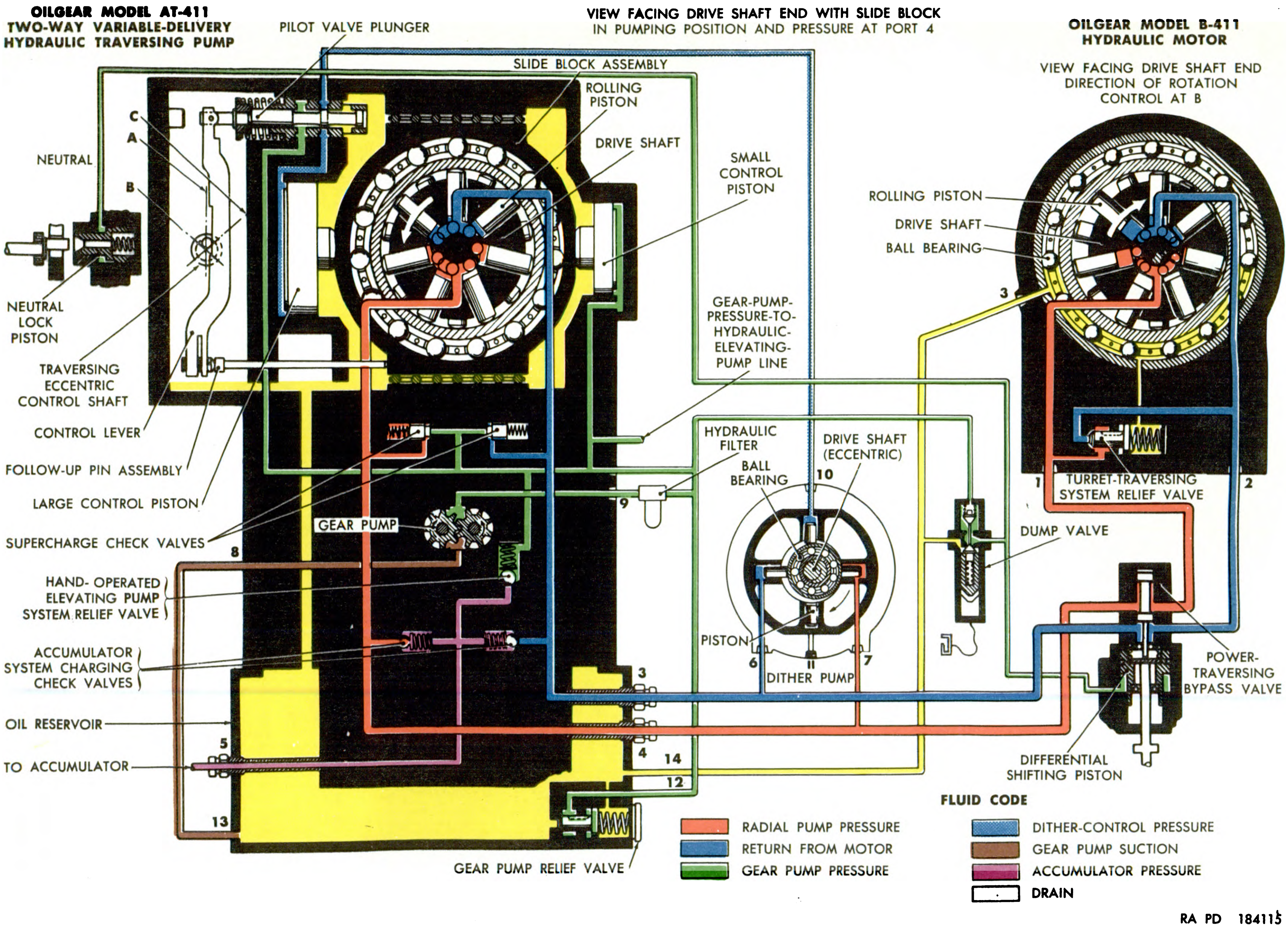

OILGEAR MODEL AT-411
TWO-WAY VARIABLE-DELIVERY
HYDRAULIC TRAVERSING PUMP
PILOT VALVE PLUNGER
VIEW FACING DRIVE SHAFT END WITH SLIDE BLOCK
IN PUMPING POSITION AND PRESSURE AT PORT 4
OILGEAR MODEL B-411
HYDRAULIC MOTOR
VIEW FACING DRIVE SHAFT END
DIRECTION OF ROTATION
CONTROL AT B
SLIDE BLOCK ASSEMBLY
ROLLING PISTON
DRIVE SHAFT
SMALL CONTROL PISTON
C
A
B
NEUTRAL
NEUTRAL LOCK PISTON
TRAVERSING ECCENTRIC CONTROL SHAFT
CONTROL LEVER
FOLLOW-UP PIN ASSEMBLY
LARGE CONTROL PISTON
SUPERCHARGE CHECK VALVES
HAND- OPERATED ELEVATING PUMP SYSTEM RELIEF VALVE
ACCUMULATOR SYSTEM CHARGING CHECK VALVES
OIL RESERVOIR
TO ACCUMULATOR
GEAR PUMP
GEAR-PUMP-PRESSURE-TO-HYDRAULIC-ELEVATING-PUMP LINE
HYDRAULIC FILTER
BALL BEARING
DRIVE SHAFT (ECCENTRIC)
PISTON
DITHER PUMP
ROLLING PISTON
DRIVE SHAFT
BALL BEARING
TURRET-TRAVERSING SYSTEM RELIEF VALVE
DUMP VALVE
POWER-TRAVERSING BYPASS VALVE
DIFFERENTIAL SHIFTING PISTON
GEAR PUMP RELIEF VALVE
1
2
3
3
4
5
6
7
8
9
10
11
12
13
14
FLUID CODE
RADIAL PUMP PRESSURE
RETURN FROM MOTOR
GEAR PUMP PRESSURE
DITHER-CONTROL PRESSURE
GEAR PUMP SUCTION
ACCUMULATOR PRESSURE
DRAIN
RA PD 184115

Figure 564. Turret traverse hydraulic system—clockwise rotation of hydraulic motor.

traverse the turret by hand. However, to do this easily, the hydraulic pressure in the system must be released and the traversing control eccentric shaft must be locked in neutral. This occurs as the crank handle is gripped, since the action closes a switch that energizes the dump-valve solenoid. With the solenoid energized, the dump valve is opened to release the pressure back of the differential shifting piston (lower right in fig. 564). A spring forces the piston down, permitting the power-traversing bypass valve to move down and connect the two hydraulic lines to the motor. There can be no pressure differential in the two lines and the motor will offer no resistance to the mechanical rotation of the traversing crank handle. At the same time, the dump valve, in opening, releases the pressure ahead of the neutral lock piston (at upper left in fig. 564). The piston is, therefore, moved up by spring pressure to move the eccentric pin in the eccentric control shaft into the neutral position and lock it there. This locking device can also be seen in (V), (W), (X), and (BB), figure 560.

d. Gun Elevating Hydraulic System.

(1) The gun elevating hydraulic system is shown schematically in figure 565. It consists essentially of the following parts: hydraulic pump driven by the electric motor in the powerpack, gear pump driven by the same motor, dither pump driven by the same motor, elevating cylinder, various controls and valves, and hydraulic lines connecting the components.

(2) The hydraulic pump is very similar in construction and operation to the turret traverse hydraulic pump, described in *c* (2) above. The control mechanism for the gun elevating system is described in paragraph 323. The control causes the hydraulic pump slide block to be moved from neutral to one side or the other, thereby directing oil under pressure from the hydraulic pump into one end or the other of the gun elevating cylinder. This elevates or depresses the gun. The amount of slide-block displacement from neutral determines the speed with which the gun moves.

(3) The gun elevating cylinder (fig. 566) consists essentially of an outer cylinder in which there is a double-ram piston. One end of the piston is connected through a bearing to the turret. The cylinder is mounted in gimbals and attached to the gun by mounting brackets. Drilled passages open into the cylinder on either side of the piston. As oil under pressure is directed to one or the other side of the piston, the piston is forced to move one way or the other in the cylinder. This movement causes the gun to be elevated or depressed. As mentioned in (2) above, the hydraulic pump supplies oil under pressure to one or the other end of the cylinder to produce this effect.

(4) The dither pump and its purpose are described in *c*(6) above.

(5) In case of power failure, the gun can be elevated or depressed by operation of the hand-operated supercharge pump to build up pressure in the accumulator, and then by operation of the hand-operated elevating pump. These are described in paragraph 326.

325. Hydraulic and Manual Turret Traverse Operation

(fig. 567)

a. General. The complete gearing system for both hydraulic and manual traversing of the turret is shown in figure 567. The rotary motion from either the hydraulic motor assembly (C) or the traversing crank handle (J) is carried through a gear train and two planetary gear systems to two traversing pinion gears (MM and JJ) that are meshed with the turret ring gear (HH) which is bolted to the tank hull. Rotation of the pinion gears causes the turret to traverse. The two planetary gear systems are employed so as to produce an antilash action between the two traversing pinion gears and the turret ring gear. This is accomplished by driving one gear directly through the gearing and the other gear through a gear backlash spring (CC). The gear backlash spring imposes a torque on one of the traversing pinion gears that takes up any backlash, and thus assures accurate turret traverse.

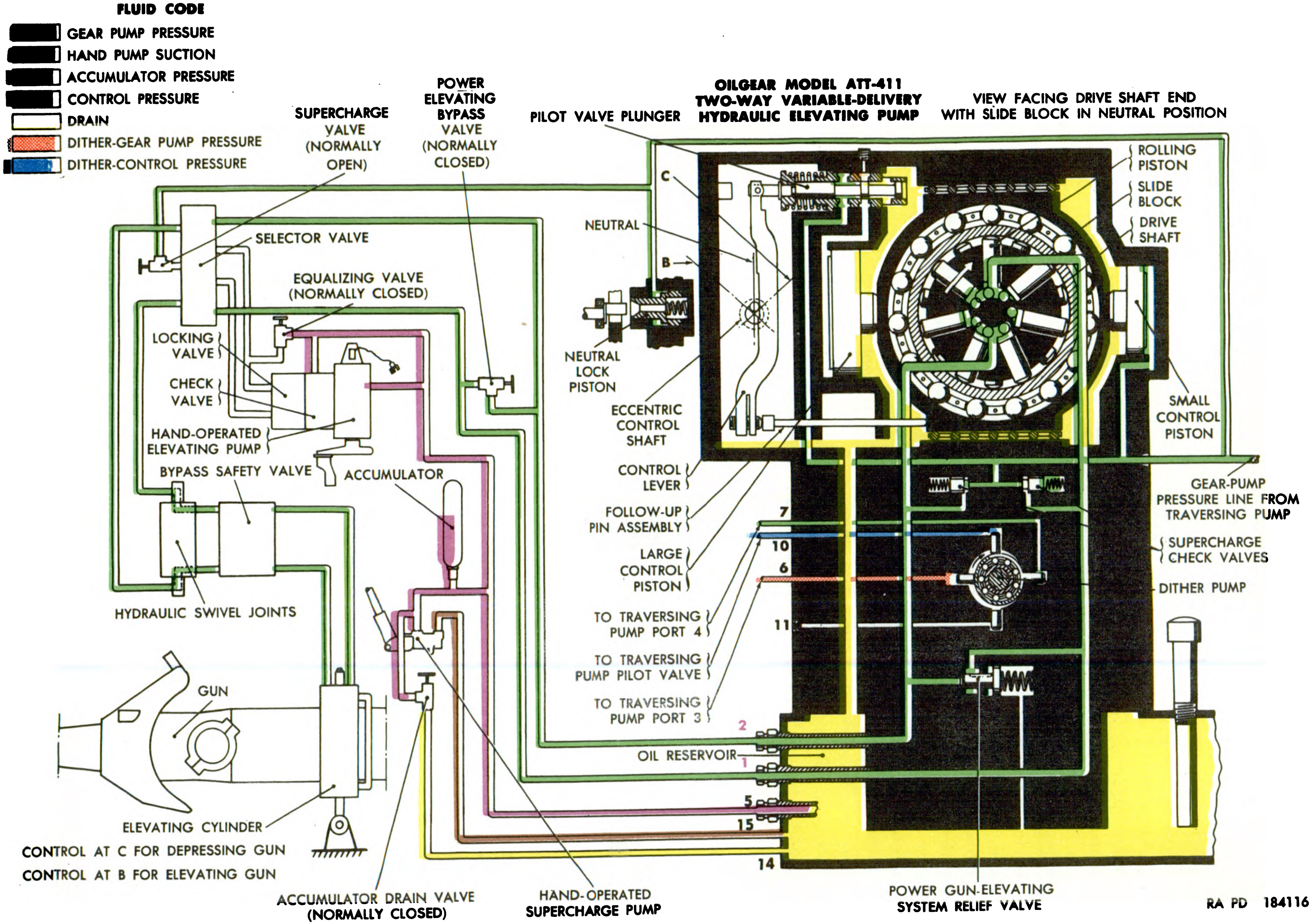

FLUID CODE
GEAR PUMP PRESSURE
HAND PUMP SUCTION
ACCUMULATOR PRESSURE
CONTROL PRESSURE
DRAIN
DITHER-GEAR PUMP PRESSURE
DITHER-CONTROL PRESSURE
SUPERCHARGE VALVE (NORMALLY OPEN)
POWER ELEVATING BYPASS VALVE (NORMALLY CLOSED)
PILOT VALVE PLUNGER
OILGEAR MODEL ATT-411 TWO-WAY VARIABLE-DELIVERY HYDRAULIC ELEVATING PUMP
VIEW FACING DRIVE SHAFT END WITH SLIDE BLOCK IN NEUTRAL POSITION
ROLLING PISTON
SLIDE BLOCK
DRIVE SHAFT
SELECTOR VALVE
EQUALIZING VALVE (NORMALLY CLOSED)
C
NEUTRAL
B
LOCKING VALVE
CHECK VALVE
HAND-OPERATED ELEVATING PUMP
NEUTRAL LOCK PISTON
ECCENTRIC CONTROL SHAFT
SMALL CONTROL PISTON
BYPASS SAFETY VALVE
ACCUMULATOR
CONTROL LEVER
FOLLOW-UP PIN ASSEMBLY
GEAR-PUMP PRESSURE LINE FROM TRAVERSING PUMP
7
10
6
SUPERCHARGE CHECK VALVES
LARGE CONTROL PISTON
DITHER PUMP
HYDRAULIC SWIVEL JOINTS
TO TRAVERSING PUMP PORT 4
11
TO TRAVERSING PUMP PILOT VALVE
GUN
TO TRAVERSING PUMP PORT 3
2
OIL RESERVOIR
1
5
15
14
ELEVATING CYLINDER
CONTROL AT C FOR DEPRESSING GUN
CONTROL AT B FOR ELEVATING GUN
ACCUMULATOR DRAIN VALVE (NORMALLY CLOSED)
HAND-OPERATED SUPERCHARGE PUMP
POWER GUN-ELEVATING SYSTEM RELIEF VALVE
RA PD 184116

Figure 565. Hydraulic gun elevating system—schematic view.

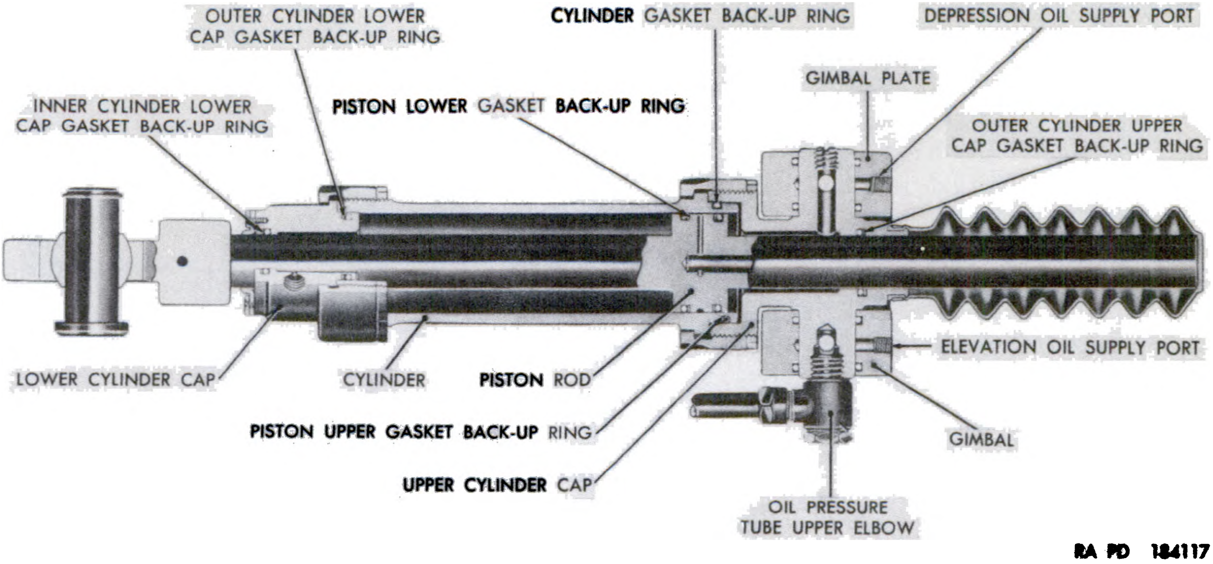
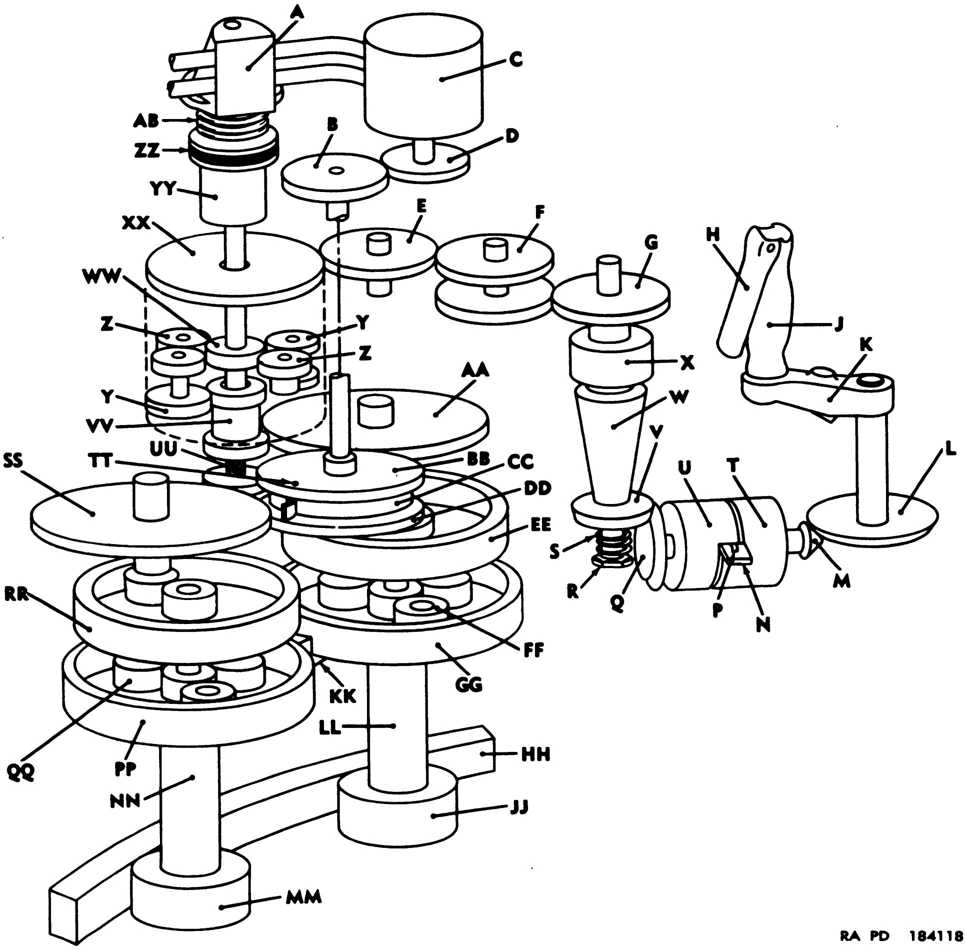

OUTER CYLINDER LOWER CAP GASKET BACK-UP RING
CYLINDER GASKET BACK-UP RING
DEPRESSION OIL SUPPLY PORT
GIMBAL PLATE
INNER CYLINDER LOWER CAP GASKET BACK-UP RING
PISTON LOWER GASKET BACK-UP RING
OUTER CYLINDER UPPER CAP GASKET BACK-UP RING
ELEVATION OIL SUPPLY PORT
LOWER CYLINDER CAP
CYLINDER
PISTON ROD
PISTON UPPER GASKET BACK-UP RING
GIMBAL
UPPER CYLINDER CAP
OIL PRESSURE TUBE UPPER ELBOW
RA PD 184117

Figure 566. Gun elevating cylinder—cross sectional view.

b. Manual Drive Power Path. When the traversing crank handle (J) is grasped, a switch is closed that releases hydraulic pressure in the hydraulic motor and hydraulic system (par. 324*c* (7)). This keeps hydraulic pressure from impeding manual traversing. The drive is from the crank handle through the gear train. In operation one of the two traversing pinion gears (either JJ or MM) is carrying the drive to the turret ring gear (HH) while the other traversing pinion gear is applying antilash torque to the turret ring gear. For example, if the crank handle is turned clockwise, pinion gear (JJ) carries the drive to the turret ring gear so the turret traverses in a clockwise direction with pinion gear (MM) applying antilash torque. But if the crank handle is turned counterclockwise, pinion gear (MM) carries the drive to the turret ring gear for counterclockwise turret traverse, with pinior gear (JJ) applying antilash torque. The antilash torque is applied by means of the gear backlash spring (CC), through either the right drive gear (AA) or the left drive gear (SS). In essence, what the gear backlash spring does is to keep one of the pinion gears in reverse tension so that it opposes turret rotation. Thus, during clockwise rotation, pinion gear (JJ) drives, but the gear backlash spring (CC) attempts to turn the other pinion gear (MM) in the opposite direction so that as much as 170 pound-feet of reverse torque is applied. This reverse, or toe-in, torque does not greatly impede turret traverse; it simply takes up any backlash in the gear train and eliminates looseness that would affect accurate turret traverse.

c. Power Operation. When the traversing crank handle (J) is released, the system prepares for power operation. Releasing the crank handle opens a switch and the solenoid in the dump valve is deenergized so the dump valve closes. Now, pressure from the powerpack gear pump (fig. 563) enters the differential shifting piston and operates the power-traversing bypass valve so that pressure differentials from the hydraulic pump can again affect the hydraulic motor. At the same time the pressure moves the neutral lock piston (upper right in fig. 563) so that the traversing eccentric control shaft is unlocked. In addition to all this, operation of the differential shifting piston (YY) lifts the differential shift-shaft gear (WW) so it is unmeshed from the planet gears (FF and QQ), thereby disconnecting the gear train from the traversing crank handle. Power to run the turret traversing gear train comes from the hydraulic motor assembly (C) and the manual drive power path is disconnected. Power travels from the hydraulic motor through gears (JJ and MM) to the motor drive drum gear (BB) and from there through the remainder of the gear system to the turret gear (HH). The antilash effect of the gear backlash spring (CC) is imposed as described in *b* above.



RA PD 184118

A	Power-bypass valve assy
B	Motor driven gear
C	Hydraulic motor assy
D	Motor drive gear
E	Single idler gear
F	Double idler gear
G	Manual drive gear
H	Grip handle lever
J	Traversing crank handle
K	Traversing crank arm
L	Hand crank bevel gear
M	Hand drive bevel gear
N	Lock bar
P	Lock spring
Q	No-back bevel gear
R	Adjustable clutch nut
S	Slip clutch ring
T	Drive bearing
U	Driven bearing
V	Clutch bevel gear
W	Female clutch housing
X	Male clutch shaft
Y	Differential double planet gear
Z	Differential single planet gear
AA	Right drive gear
BB	Motor drive drum gear
CC	Gear backlash spring
DD	Lower backlash gear
EE	Planetary drive internal gear
FF	Planet drive gear
GG	Planetary ring gear
HH	Turret ring gear
JJ	Traversing pinion gear
KK	Planetary ring gear key
LL	Main drive shaft
MM	Traversing pinion gear
NN	Main drive shaft
PP	Planetary ring gear
QQ	Planet drive gear
RR	Planetary drive internal gear
SS	Left drive gear
TT	Motor drive drum gear pin
UU	Differential output splined gear
VV	Differential double output gear
WW	Differential shift-shaft gear
XX	Differential cage gear
YY	Differential shifting piston
ZZ	Hydraulic piston seal
AB	Manual return piston spring

Figure 567. Power and hand turret traversing mechanism.

326. Hand Operation of Gun Elevating System

a. General. When the powerpack is inoperative, hydraulic pressure is lost. The hand-operated supercharge pump and the hand-operated elevating pump (fig. 565) can be used under this condition to elevate or depress the gun.

b. Selector Valve. When hydraulic pressure is lost, due to stopping of the powerpack, the pistons in the selector valve are moved by spring pressure so as to shut off the hydraulic circuits to the hydraulic pump and open the hydraulic circuits to the hand-operated gun elevating system. On the other hand, when the hydraulic pump starts and begins to deliver pressure to the selector valve, this pressure moves the selector valve pistons against their spring pressure so as to shut off the hydraulic circuits to the hand-operated gun elevating system and, at the same time, to open the hydraulic circuits to the hydraulic pump.

c. Hand-Operated Supercharge Pump. To produce hydraulic pressure in the gun elevating hydraulic system, in the absence of pressure from the hydraulic pump, the hand-operated supercharge pump (fig. 565) is operated. As the pump handle is moved back and forth, the pump piston moves in the pump cylinder. Oil is withdrawn from the reservoir in the powerpack and delivered to the accumulator. In this way, pressure is built up in the hand-operated gun elevating system.

d. Accumulator. The accumulator is a cylinder which contains a bag filled with nitrogen gas at high pressure. Oil pressure introduced into the accumulator by the hand-operated supercharge pump causes the nitrogen-filled bag to be compressed. As oil, under pressure, enters the accumulator, the nitrogen-filled bag is further compressed. Thus, oil pressure is increased and a quantity of oil is stored in the accumulator under pressure. The accumulator acts as a high-pressure storage reservoir. In addition, it can supply this high-pressure oil to the system on demand.

e. Hand-Operated Elevating Pump. The elevating pump is a constant-displacement, reversible, multiple-cylinder unit. Its purpose is to increase pressure on one side and reduce pressure on the other side of the gun elevating cylinder to cause gun elevation or depression. When the crank handle of the pump is turned in one direction, oil pressure is increased on one side of the gun elevating cylinder so that the gun is elevated. But if the crank handle is turned in the other direction, oil pressure is increased on the other side and the gun is depressed. The pump works with the high pressure already in the system, produced by the hand-operated supercharge pump and stored in the accumulator. In operation, the elevating pump simply increases this pressure in one side of the elevating cylinder and reduces it in the other side.

PART SIX

SPECIAL EQUIPMENT UNITS

CHAPTER 24

ACCESSORIES

327. Power-Take-Off

a. A power take-off is an attachment for connecting the engine to power-driven auxiliary machinery when its use is required. It is attached to the transmission, auxiliary transmission, or transfer case. A power-take-off installed at the left side of a transmission is shown in figure 568. It is used to drive a winch, located at the front of the truck, through a universal joint and propeller shaft.

b. The simplest type of transmission power-take-off is the single-gear, single-speed type shown in figures 569 and 570. This unit is bolted over an opening provided for the purpose at the side of the transmission case. This opening is closed by a cover plate when no power-take-off is used. The opening in the transmission case and the power-take-off gear meshes with a gear on the transmission countershaft. As shown in figure 569, the gear slides on the splined main shaft, off which the power is taken. The shifter shaft, controlled by a lever in the driver's cab, slides the gear in and out of mesh with the countershaft gear. Since it is driven by the countershaft, the power-take-off shaft rotates in the same direction as the engine crankshaft.

c. Transmission power-take-offs are available in several different designs: a single-speed, two-gear model in which the rotation of the power-take-off shaft is opposite to that of the engine; a model having a single speed forward and reverse; and a model having two speeds forward and one reverse. Several different mountings are also available.

d. The same types of power-take-offs are also applied to auxiliary transmissions. Figure 571 shows a winch driven off an auxiliary transmission.

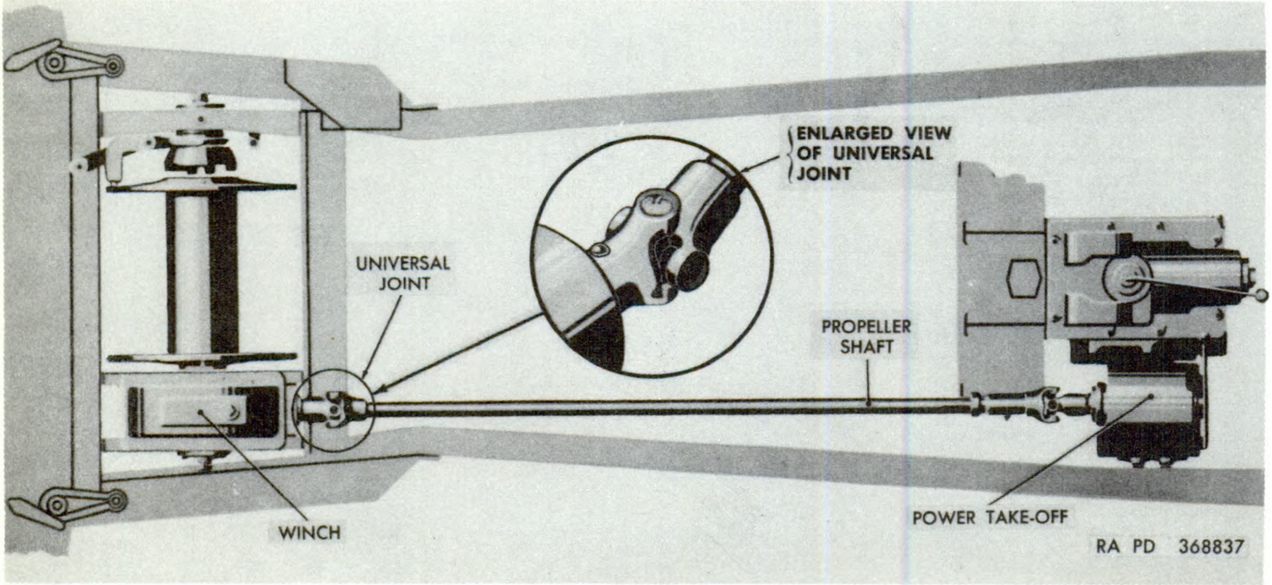


Figure 568. Winch and power take-off installation.

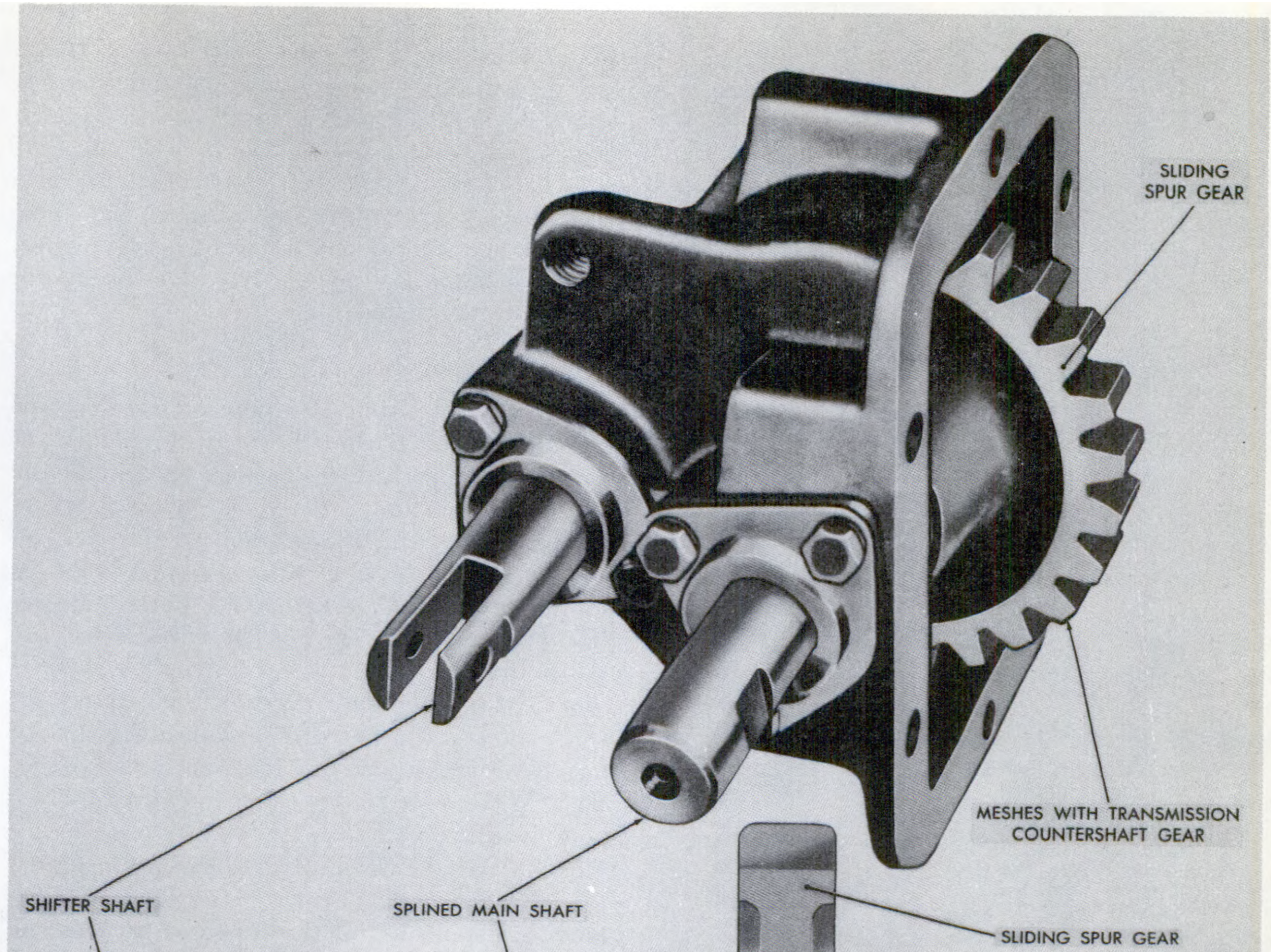

SLIDING SPUR GEAR
MESHES WITH TRANSMISSION COUNTERSHAFT GEAR
SHIFTER SHAFT
SPLINED MAIN SHAFT
SLIDING SPUR GEAR
POPPET
RA PD 184120

Figure 569. Single-speed, single-gear power take-off.

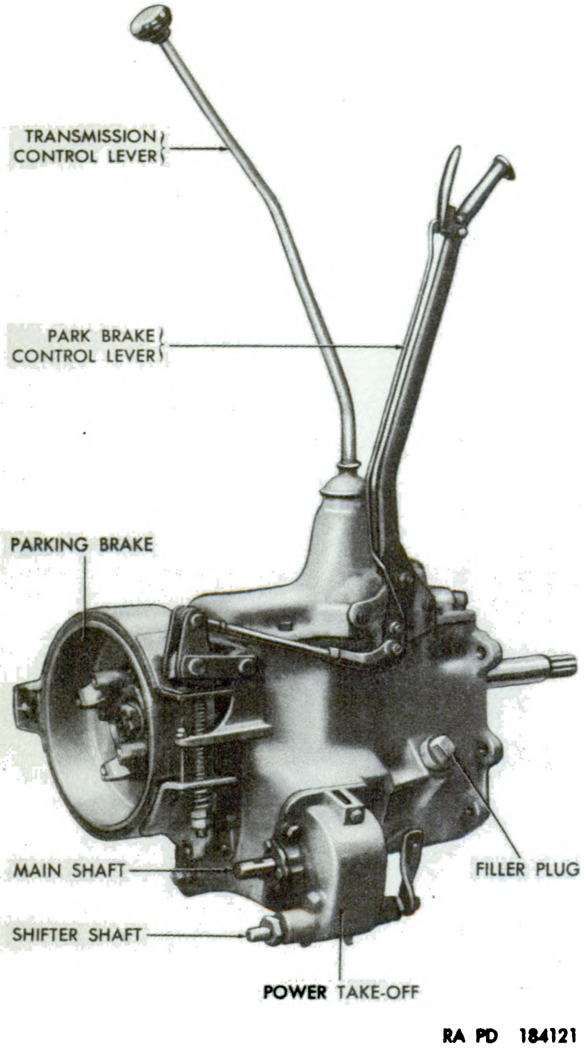


Figure 570. Single-speed, single-gear power take-off—installed view.

e. Power is sometimes taken off a transfer case. The transfer case drive shaft, which is connected to the transmission, extends through the case, and the power-take-off shaft is engaged to it by a dog clutch. This transfer case has two speeds and a neutral position. It is necessary to put the transfer case sliding gear in the neutral position if the vehicle is to be stationary while the power-take-off is in use. If the power-take-off is needed while the vehicle is in motion, the transfer case may be shifted either into high or low range. With this arrangement, the power-take-off will work on any speed of the transmission. The positions of all the cab control levers of one model of vehicle are shown diagrammatically in figure 572 as they are placed on the instruction plate in the cab. When the power-take-off clutch is engaged, the winch capstan operates; but the winch drum does not rotate until the winch clutch is engaged.

f. The several types of power-take-offs have been described as operating winches, but their uses for operating various kinds of hoists, pumps, and other auxiliary power-driven machinery are essentially the same.

328. Winches

a. Purpose. Using its winch and some type of rigging, a vehicle can pull itself or another vehicle through such an obstacle as very muddy or very rough terrain. This is the primary reason for providing winches on standard military vehicles. The winch in this case is powered by the engine of the vehicle through a power take-off from the transmission. Field expedients may utilize the winch for such devices as simple cranes in a field shop. However, on special equipment and vehicles, winches are furnished for special purposes such as powering the crane of a wrecker. Some of these latter winches are powered by separate gasoline engines.

b. Mounting. Generally, the winch is mounted behind the front bumper and is secured to the front cross member of the frame or between the two side frame rails. It may be mounted behind the cab. The tandem winch assembly, for example, consists of a front (upper) and rear (lower) winch that is secured to a mounting assembly fastened to the chassis frame at the rear of the cab.

c. Operation. The typical front-mounted winch is a jaw-clutch worm-gear type. The winch consists of a worm and shaft which drives a worm gear that is keyed to a shaft (fig. 573). A bushed drum is mounted on the worm gear shaft which is controlled by a sliding clutch. The worm shaft is driven by a drive shaft connected to a power-take-off unit mounted on the transmission. The hand-operated sliding clutch is keyed to the worm gear shaft outside of the winch drum, and must be engaged with the jaws on the side of the winch drum when the winch is to be operated. Disengagement of the sliding clutch permits the drum to turn on the worm gear shaft. Two brakes are provided to control the winch drum. The worm shaft brake prevents the winch drum from rotating under load, when the power take-off is disengaged. The shifter bracket brake prevents the drum overrun-

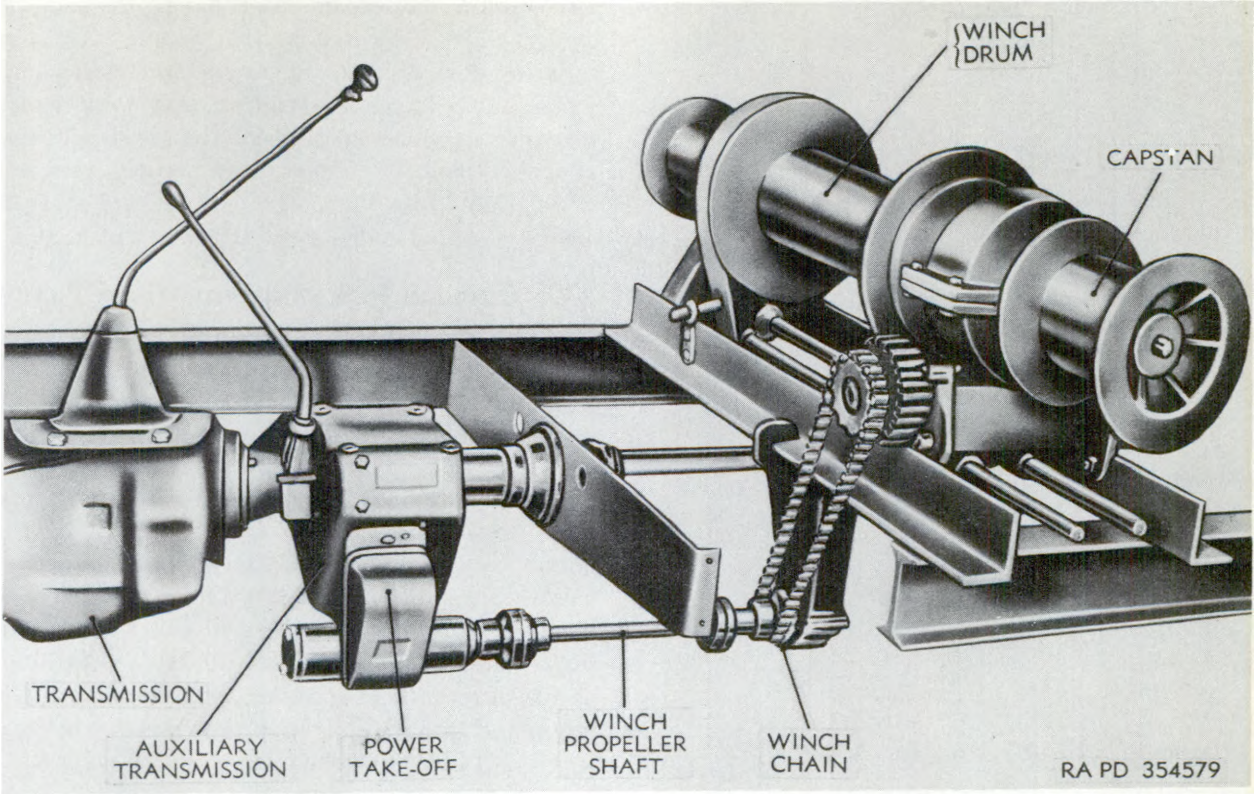


Figure 571. Auxiliary transmission power-take-off driving winch.

ning the cable when the cable is being unreeled. A shear pin on the worm drive shaft prevents damage from overloading. The power-take-off is controlled by a shift lever located in the driver's compartment.

d. Cautions on Using Winch.

(1) Certain special precautions should be observed when a winch is used. A winch line under load actually stretches and, if it should break, it will snap back with terrific force. Whenever a winch is being used, everyone within range should stand clear at least the distance of the paidout cable.

(2) When using snatch blocks, keep away from the angle made by the cable and block. If something should let loose, the block might travel as far as 300 yards on the fly. Anybody in the way might be seriously hurt.

(3) Only standard shear pins should be used for replacement if shear pin gives way. The shear pin is so designed that it fails before the winch or line breaks. If a stronger shear pin is put in, the winch or line might be overloaded and fail.

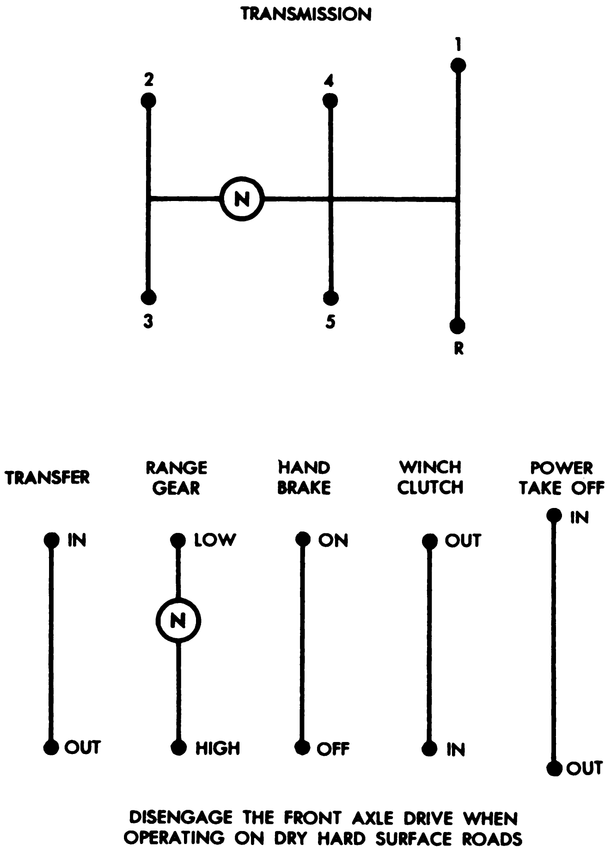
(4) Do not kink the wire rope, since this weakens it seriously. Be sure the rope is wound tight and even on the drum. When rewinding, be sure to rewind under tension. A quick way to do this is to rewind with at least two men hanging on to the end of the line.

(5) Loads should be applied slowly to avoid sudden stresses on the winch or rope. Also, the rope should be watched to make sure it does not drag over sharp rocks. The rope should be oiled occasionally to keep it from rusting. Rust weakens the rope.

e. Level Wind. Some winches may be equipped with an automatic level winding device to spool the cable on the drum in tight even coils and layers. This prevents crushing of the cable due to loose crossed coils and layers, and to allow off-leads of the cable while maintaining level winding.

329. Tire Inflation System

a. Amphibious trucks are equipped with a central tire-pressure control system, by means of



RA PD 184122

***Figure 572.** Typical shift positions of transfer and power-take-off control levers for 2-speed transfer assembly with power-take-off.*

which the tires may be inflated or deflated to meet various conditions encountered by the vehicle. When operating on sand, the tires are deflated to obtain adequate flotation; to travel on a hard surface, the tires are inflated.

b. Location of each component of the system is shown in figure 575. A 2-cylinder, water-cooled, self-lubricated pump with a capacity of 9 cfm is mounted in the front compartment and driven directly by the engine crankshaft. This maintains pressure in the air tank. It is controlled by a governor that stops the pump when maximum allowable pressure is attained and automatically starts the pump when pressure in the tank drops below a prescribed limit. Air pressure is piped from the tank to the inflation and deflation control valves assembly. When the control valve lever is placed in the "INFLATE" position, air passes through the valve to the air line manifold and valves, thence to each tire, through individual air lines and tire inflating devices. A safety valve is located in the system. The tire inflating device, or hub device, is mounted on each wheel hub. It is an airtight rotary joint which provides a connection between the air supply line and the tire. The inner part rotates with the wheel hub while the outer part is held stationary by a swivel-ended strut attached to the hull.

330. Gasoline-Tank and Water-Tank Pumps

a. General. Water and gasoline may be transported in tank trucks (fig. 576) or in tank semitrailers (fig. 577). Tank trucks have a special accessory drive unit mounted on the power take-off to drive the pump. Tank semitrailers have a portable pump driven by a small gasoline engine.

b. Tank Semitrailers. The locations of the portable pump and hose with which the tank semitrailers are equipped are shown in figure 578. The portable pump is shown in figure 579. The pump can be used to unload or load the tank, depending on which way the hose connections are made to the pump and tank. The pump shown is driven by a single-cylinder, 4-stroke-cycle gasoline engine.

c. Handling Gasoline.

Caution: Extreme care must be used when gasoline is being handled since it is very inflammable. Vapor from gasoline, even in the open, may become sufficiently concentrated during pumping operations to explode and bring about a disastrous fire. Smoking or open flames must not be permitted in the vicinity of fuel pumping operations. See complete instructions on handling gasoline in applicable technical manuals.

d. Tank Trucks. On the tank truck the power-take-off, which is mounted on the transfer assembly, contains a pump drive. When the driver positions the controls, the pumping equipment is set into operation. At the same time, an auxiliary engine governor comes into action to properly limit engine speed during the time that the pumping equipment is operated. This prevents overspeeding of the engine.

331. Dump Trucks

Dump trucks (fig. 580) have a steel body which pivots at the rear. The dump body pivots on two hinge pins when it is raised by a hydraulic hoist cylinder mounted on a transverse base shaft. The pressure developed in the hydraulic hoist cylinder by the operation of a special pump causes the dump

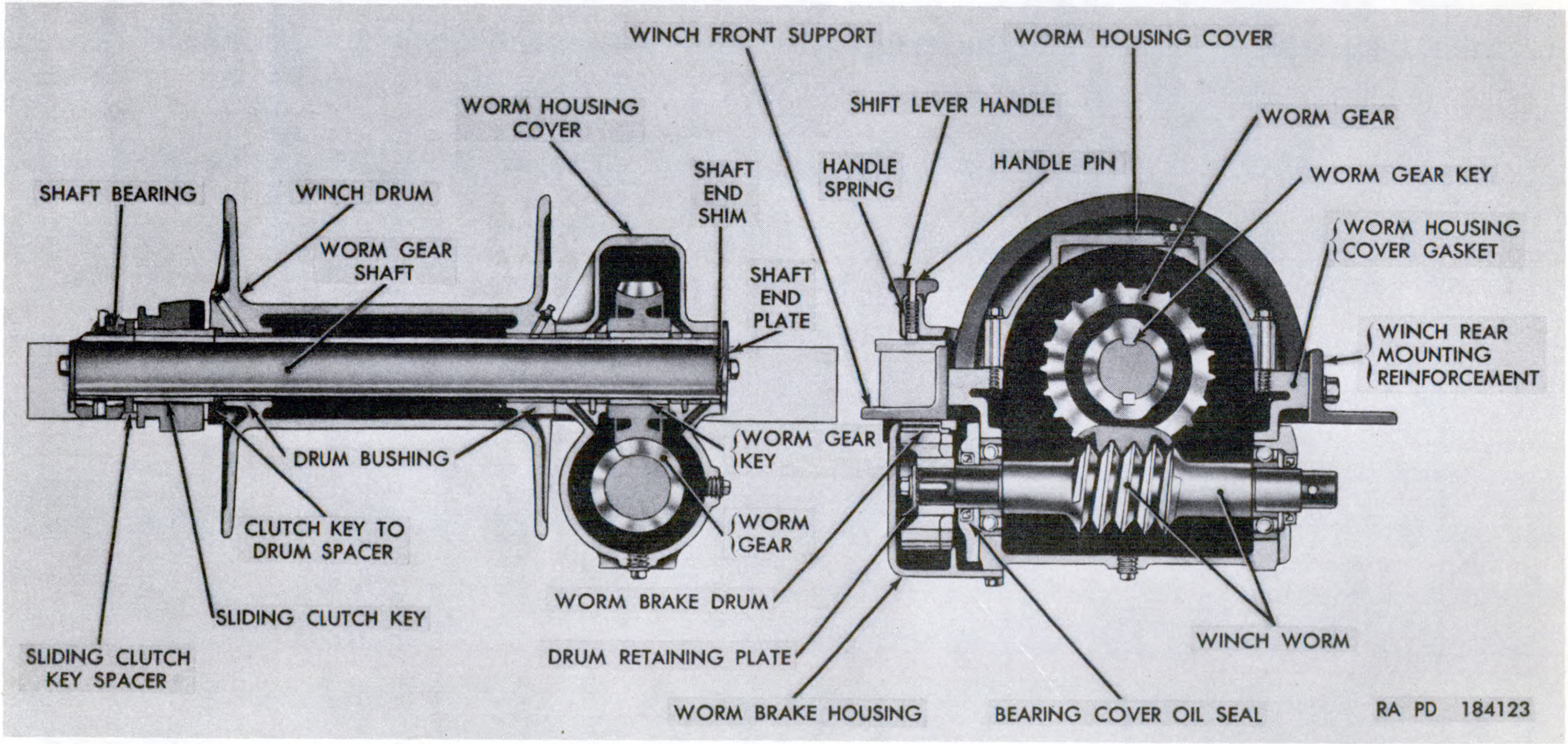

WINCH FRONT SUPPORT
WORM HOUSING COVER
WORM HOUSING COVER
SHIFT LEVER HANDLE
WORM GEAR
SHAFT BEARING
WINCH DRUM
SHAFT END SHIM
HANDLE SPRING
HANDLE PIN
WORM GEAR KEY
WORM GEAR SHAFT
WORM HOUSING COVER GASKET
SHAFT END PLATE
WINCH REAR MOUNTING REINFORCEMENT
WORM GEAR KEY
DRUM BUSHING
WORM GEAR
CLUTCH KEY TO DRUM SPACER
WORM BRAKE DRUM
SLIDING CLUTCH KEY
WINCH WORM
SLIDING CLUTCH KEY SPACER
DRUM RETAINING PLATE
WORM BRAKE HOUSING
BEARING COVER OIL SEAL
RA PD 184123

Figure 573. Jaw-clutch worm gear winch.

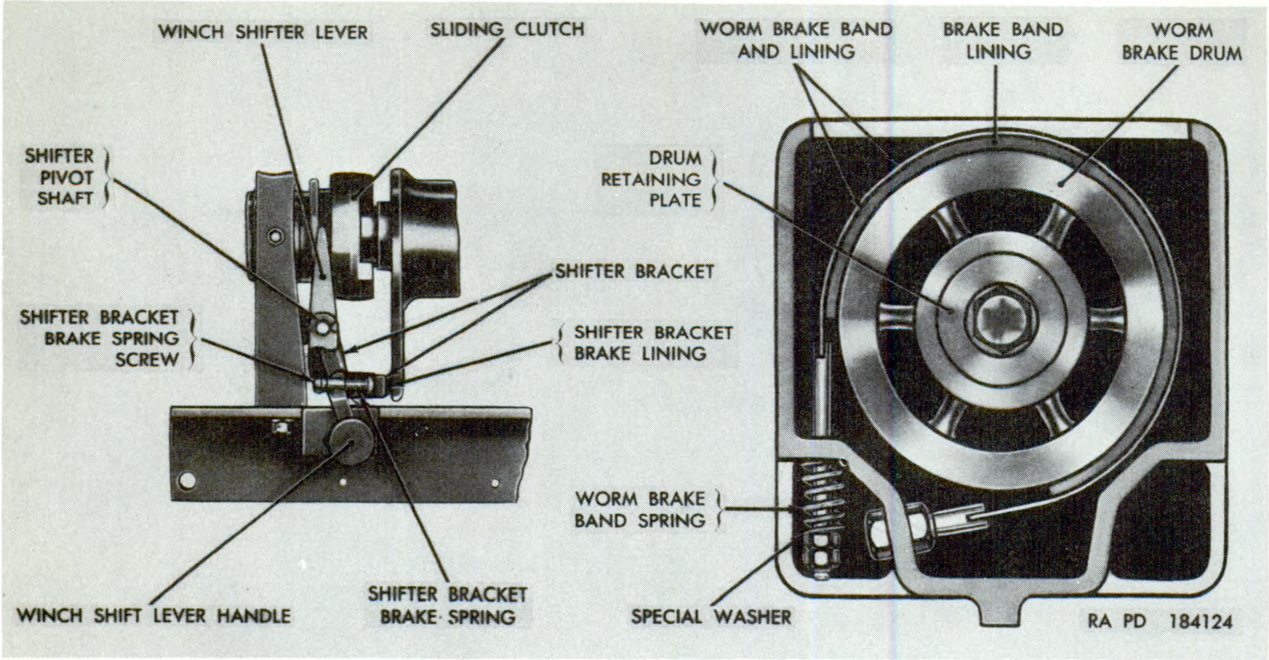

WINCH SHIFTER LEVER
SLIDING CLUTCH
WORM BRAKE BAND AND LINING
BRAKE BAND LINING
WORM BRAKE DRUM
SHIFTER PIVOT SHAFT
DRUM RETAINING PLATE
SHIFTER BRACKET
SHIFTER BRACKET BRAKE SPRING SCREW
SHIFTER BRACKET BRAKE LINING
WORM BRAKE BAND SPRING
WINCH SHIFT LEVER HANDLE
SHIFTER BRACKET BRAKE SPRING
SPECIAL WASHER
RA PD 184124

Figure 574. Winch clutch and brake.

body to move up into the position shown in figure 581. Since the hydraulic cylinder is double acting, it is also used to hold or lower the dump body. The endgate (fig. 582) normally is pivoted at the top, and is secured in this position by lock pins through endgate upper latches. Lower latches hold the endgate closed until they are released by the hand lever on the front left corner of the body. The endgate is released for dumping in this manner, and the extent that it opens is controlled by adjustment of the chains in the locking slots (fig. 582).

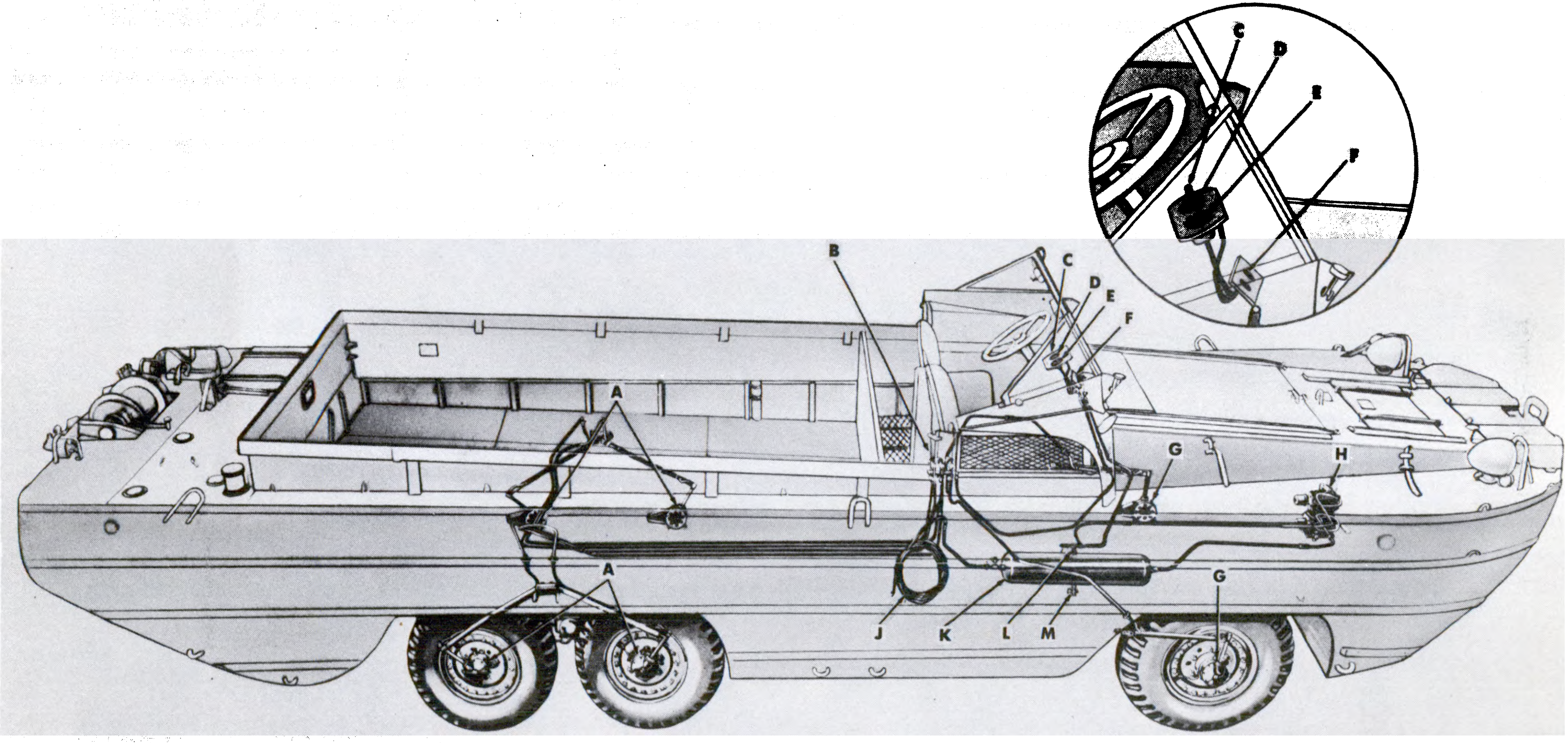
332. Dump Truck Mechanisms

a. Body Control Box. A dump body control lever in the rear and at the left of the driver's seat operates a shift control lever connected by linkage to a control box. Figure 583 shows the control lever, while figure 584 shows the linkage between the control lever, the control box, and the power-take-off. The body control box contains two cams which move as the control lever is moved; this causes the dump body to raise, hold, or lower, according to the control lever position.

b. Dump Body Control Lever (fig. 583). The dump body control lever, located in the cab, has four positions. In the first position (A), the body is down and the power take-off is disengaged. When the control lever is moved to the next position (B), the forward arm in the control box is engaged and the shift linkage engages the power-take-off. To raise the body, the control lever is moved forward past position (C) to position (D). The lift can be stopped and the body held in any position by returning the control lever to position (C). With the lever at position (B) or (D), the body is automatically checked at either the up or down position at the limit of travel.

c. Control Valve and Pump. When the power-take-off is engaged, the pump is driven. It can now deliver hydraulic fluid to the hydraulic cylinder, provided the control valve is properly positioned. The control valve is linked to the control lever (fig. 583). When the control lever is moved to position (D, fig. 583), the control valve directs the hydraulic fluid from the pump into the front, or elevating, end of the hydraulic cylinder. The hydraulic pressure forces the piston and piston rod toward the rear of the truck. This raises the dump truck body.

d. Hydraulic Cylinder. The hydraulic cylinder is double acting and is mounted in the forward part of the truck subframe. The cylinder base is mounted on a shaft held in bearings on the in-



A—REAR TIRE INFLATING DEVICES
B—AIR LINE MANIFOLD AND VALVES ASSEMBLY
C—TIRE INFLATING CONTROL LEVER
D—TANK PRESSURE AIR GAGE
E—TIRE PRESSURE AIR GAGE
F—TIRE INFLATION AND DEFLATION CONTROL VALVES
G—FRONT TIRE INFLATING DEVICES
H—TIRE PUMP
J—TIRE INFLATING HOSE
K—AIR TANK
L—SAFETY VALVE
M—DRAIN COCK

RA PD 184125

Figure 575. Location of central tire-pressure control system components.

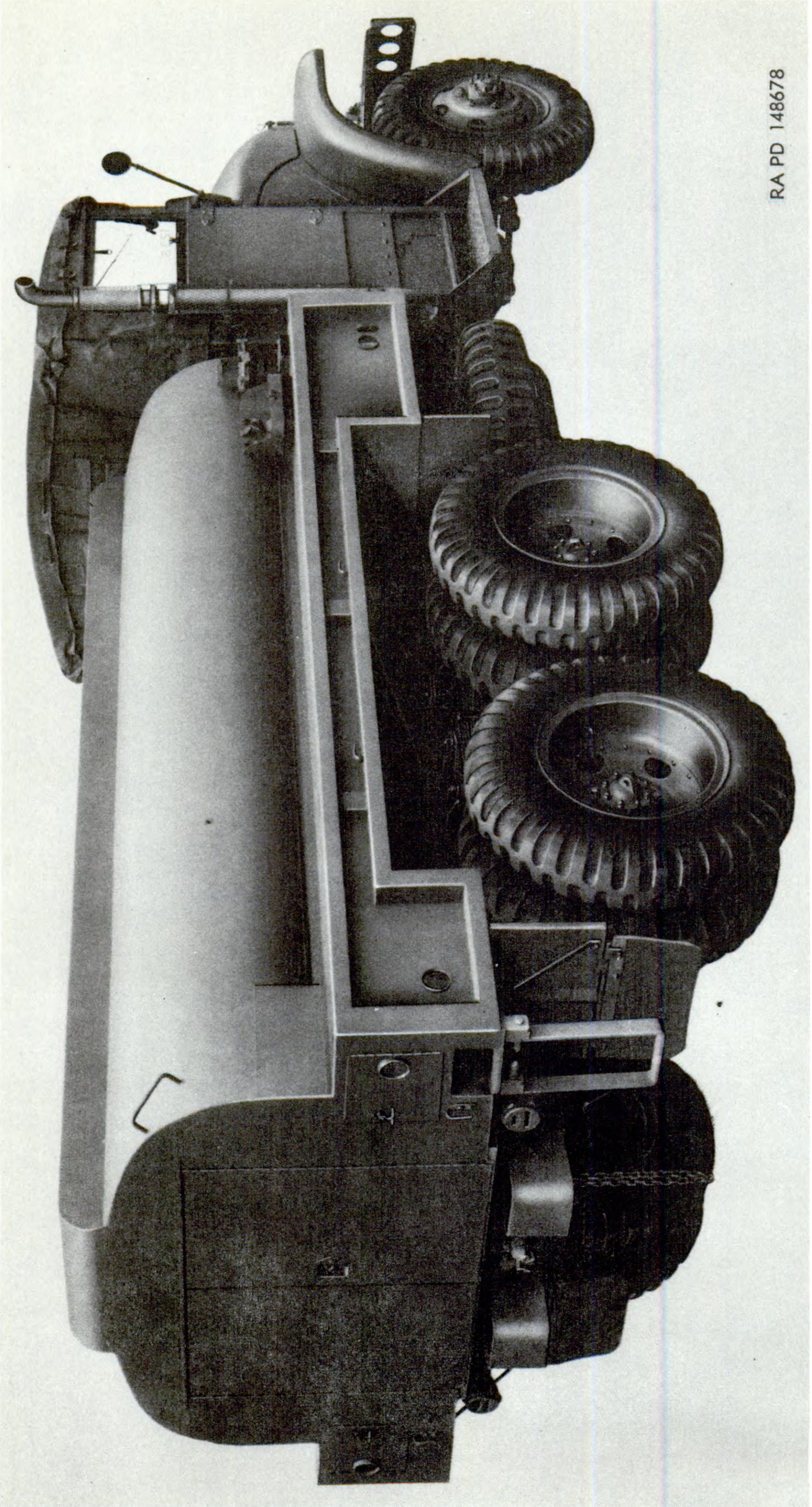

RA PD 148678

Figure 576. 2½-ton 6X6 gasoline-tank truck.

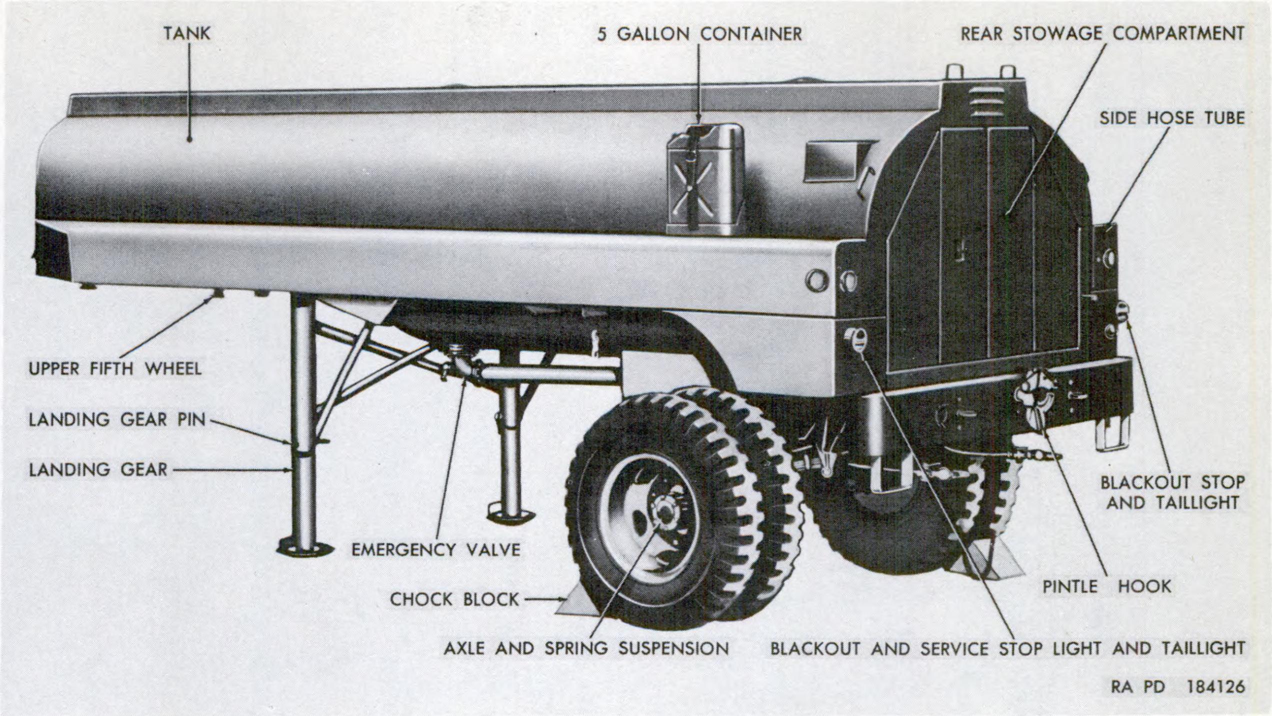

TANK
5 GALLON CONTAINER
REAR STOWAGE COMPARTMENT
SIDE HOSE TUBE
UPPER FIFTH WHEEL
LANDING GEAR PIN
LANDING GEAR
EMERGENCY VALVE
CHOCK BLOCK
AXLE AND SPRING SUSPENSION
BLACKOUT STOP AND TAILLIGHT
PINTLE HOOK
BLACKOUT AND SERVICE STOP LIGHT AND TAILLIGHT
RA PD 184126

Figure 577. 2,000-gallon tank semitrailer.

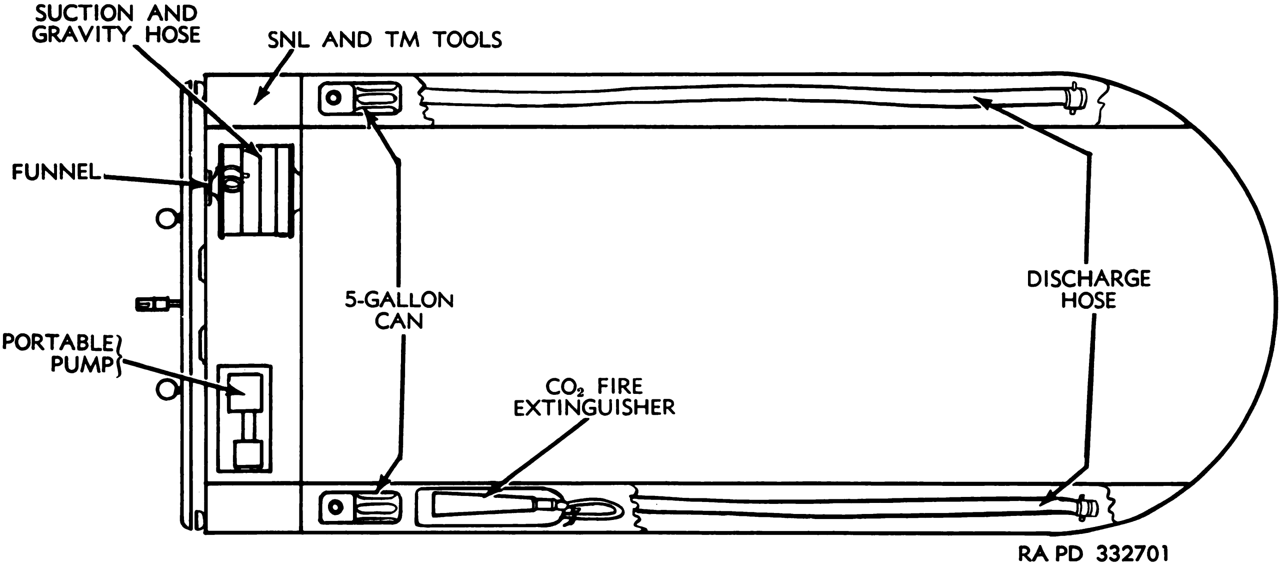

SUCTION AND GRAVITY HOSE
SNL AND TM TOOLS
FUNNEL
5-GALLON CAN
DISCHARGE HOSE
PORTABLE PUMP
CO₂ FIRE EXTINGUISHER
RA PD 332701

Figure 578. Locations of portable pump and hose in tank semitrailer.

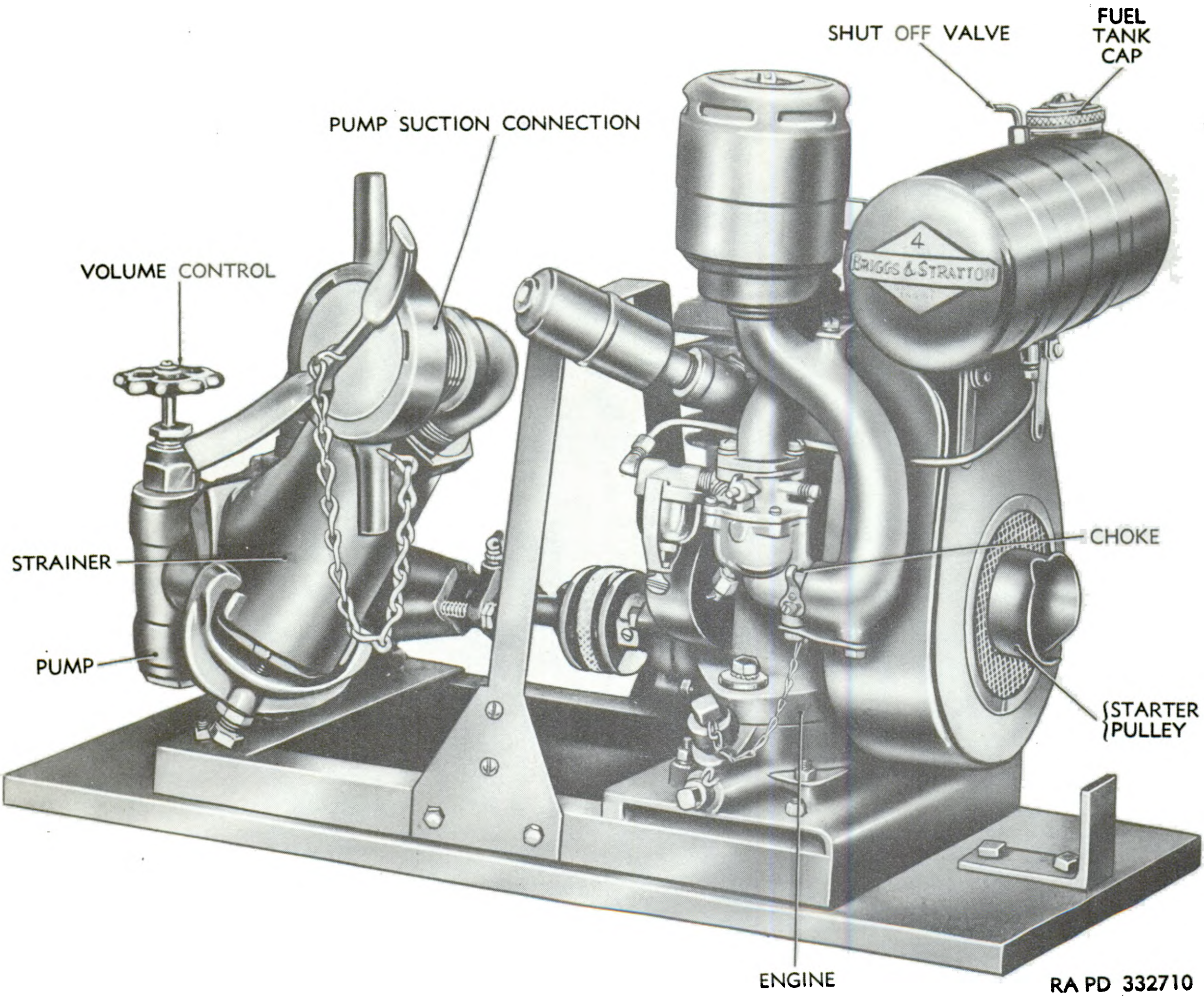

SHUT OFF VALVE
FUEL TANK CAP
PUMP SUCTION CONNECTION
VOLUME CONTROL
BRIGGS & STRATTON
STRAINER
CHOKE
PUMP
STARTER PULLEY
ENGINE
RA PD 332710

Figure 579. Portable pump.

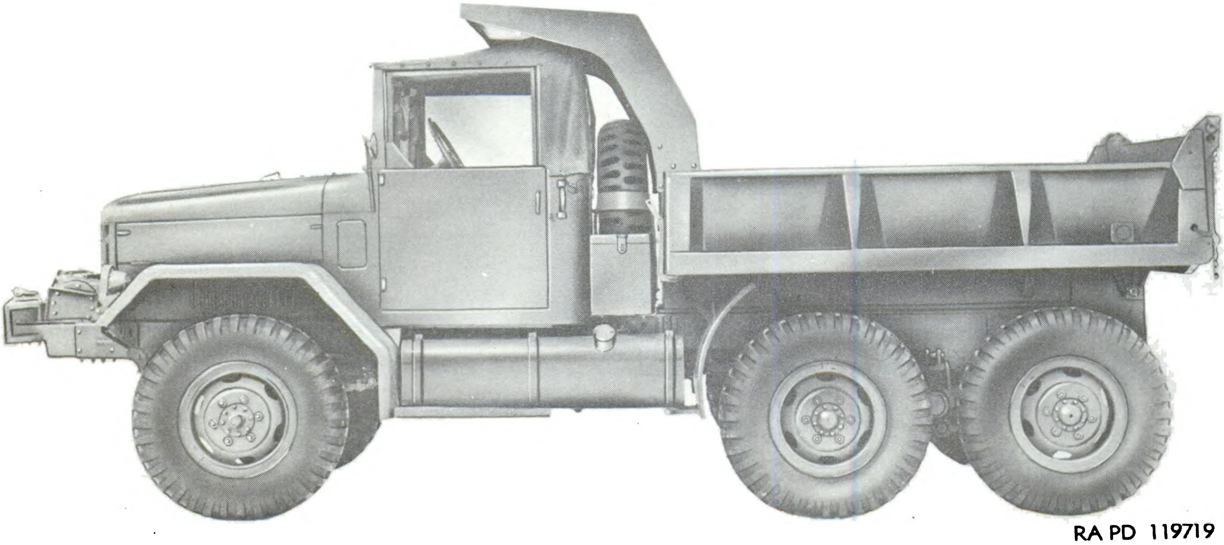

RA PD 119719

Figure 580. Dump truck—side view.

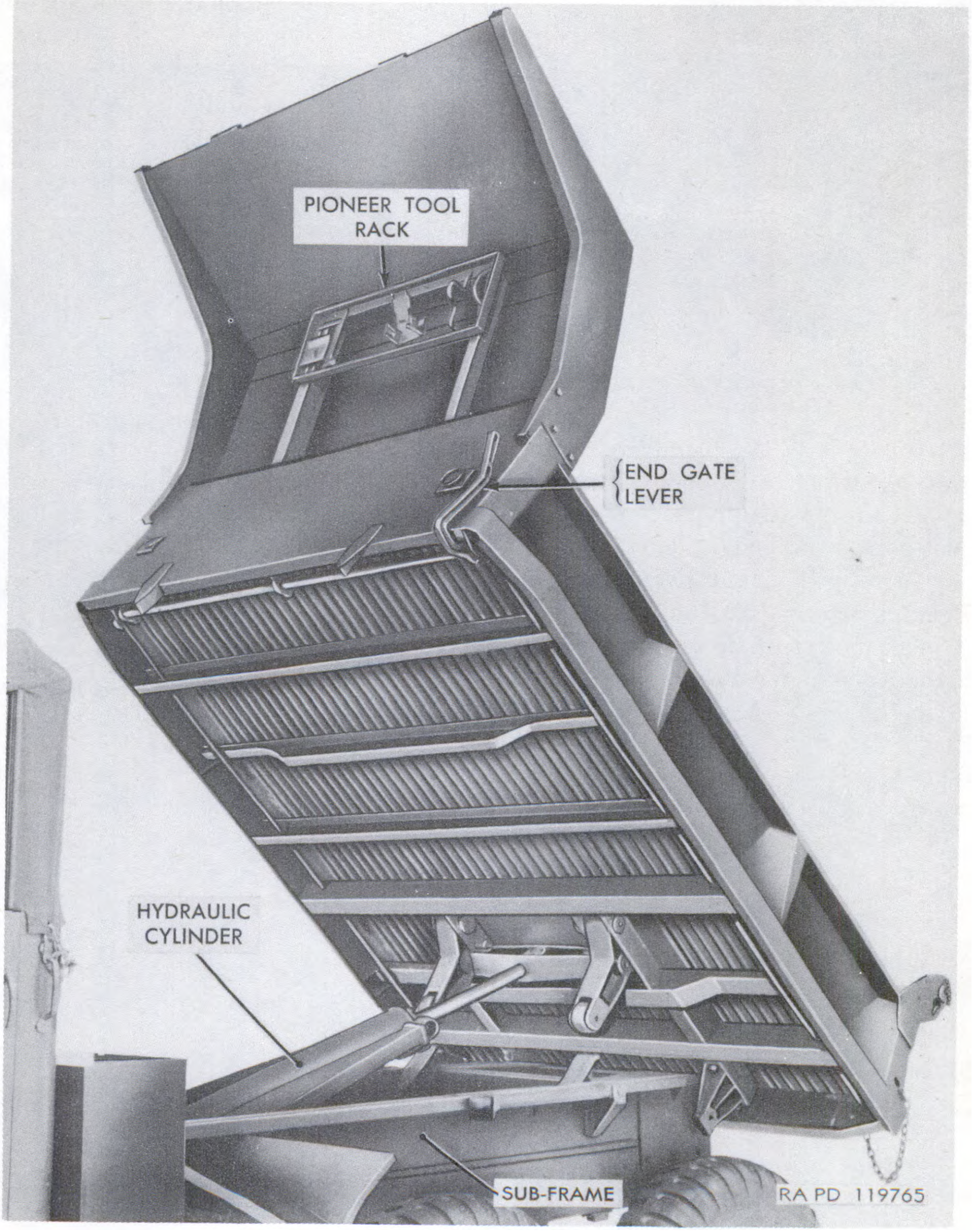

PIONEER TOOL RACK
END GATE LEVER
HYDRAULIC CYLINDER
SUB-FRAME
RA PD 119765

Figure 581. Dump body—raised.

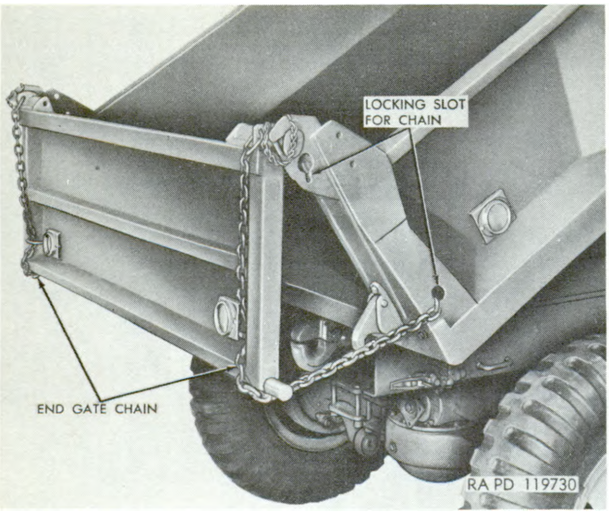

LOCKING SLOT FOR CHAIN
END GATE CHAIN
RA PD 119730

Figure 582. End gate open for dump.

ner sides of the subframe. The piston rod is connected to a crosshead which is pivoted with a roller arm on each end. Arms are supported by bearing pins on the bottom of the body. The free ends of the arms are equipped with rollers which engage curved ramps attached to the sides of the subframe. The movement of the piston rod, carried through the arms and rollers to the ramps, raises the body.

333. Wrecking Truck Equipment

a. General. Wrecking trucks (fig. 585) include front and rear winches and a crane assembly. Winches are described in paragraph 328. The crane assembly consists of a combination of units, all mounted on the crane **A**-frame (fig. 586).

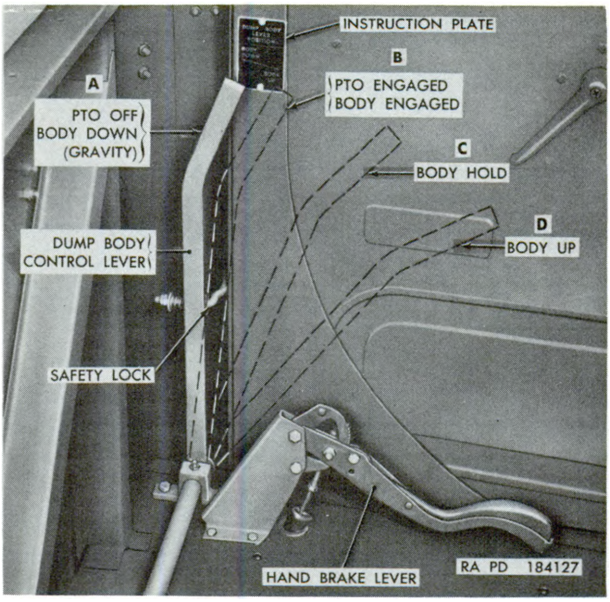

INSTRUCTION PLATE
B
PTO ENGAGED
BODY ENGAGED
A
PTO OFF
BODY DOWN
(GRAVITY)
C
BODY HOLD
D
BODY UP
DUMP BODY
CONTROL LEVER
SAFETY LOCK
HAND BRAKE LEVER
RA PD 184127

Figure 583. Dump body control lever (driver's seat removed).

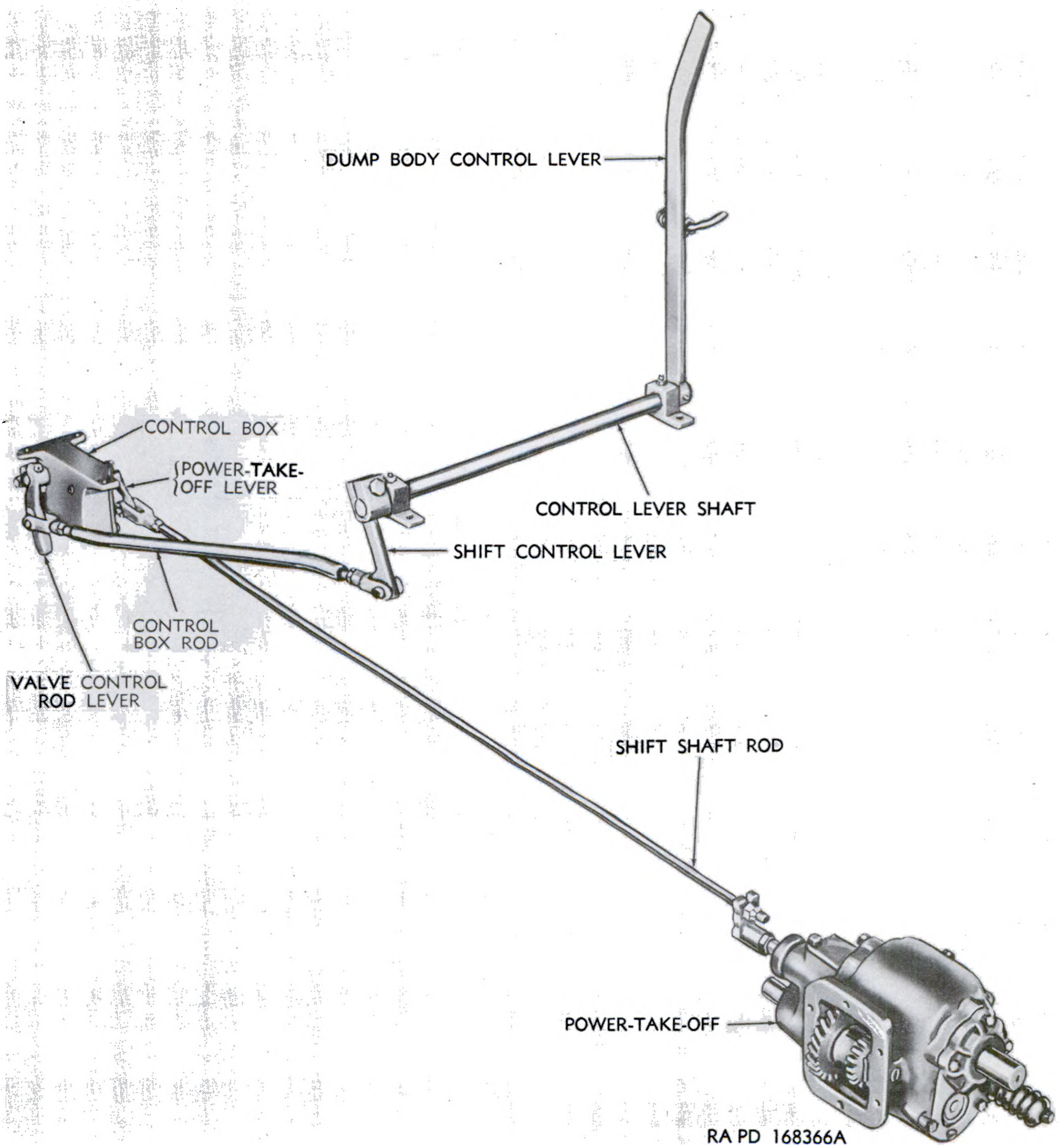

DUMP BODY CONTROL LEVER
CONTROL BOX
POWER-TAKE-OFF LEVER
CONTROL LEVER SHAFT
SHIFT CONTROL LEVER
CONTROL BOX ROD
VALVE CONTROL ROD LEVER
SHIFT SHAFT ROD
POWER-TAKE-OFF
RA PD 168366A

Figure 584. Control linkage between control lever, control box, and power-take-off.

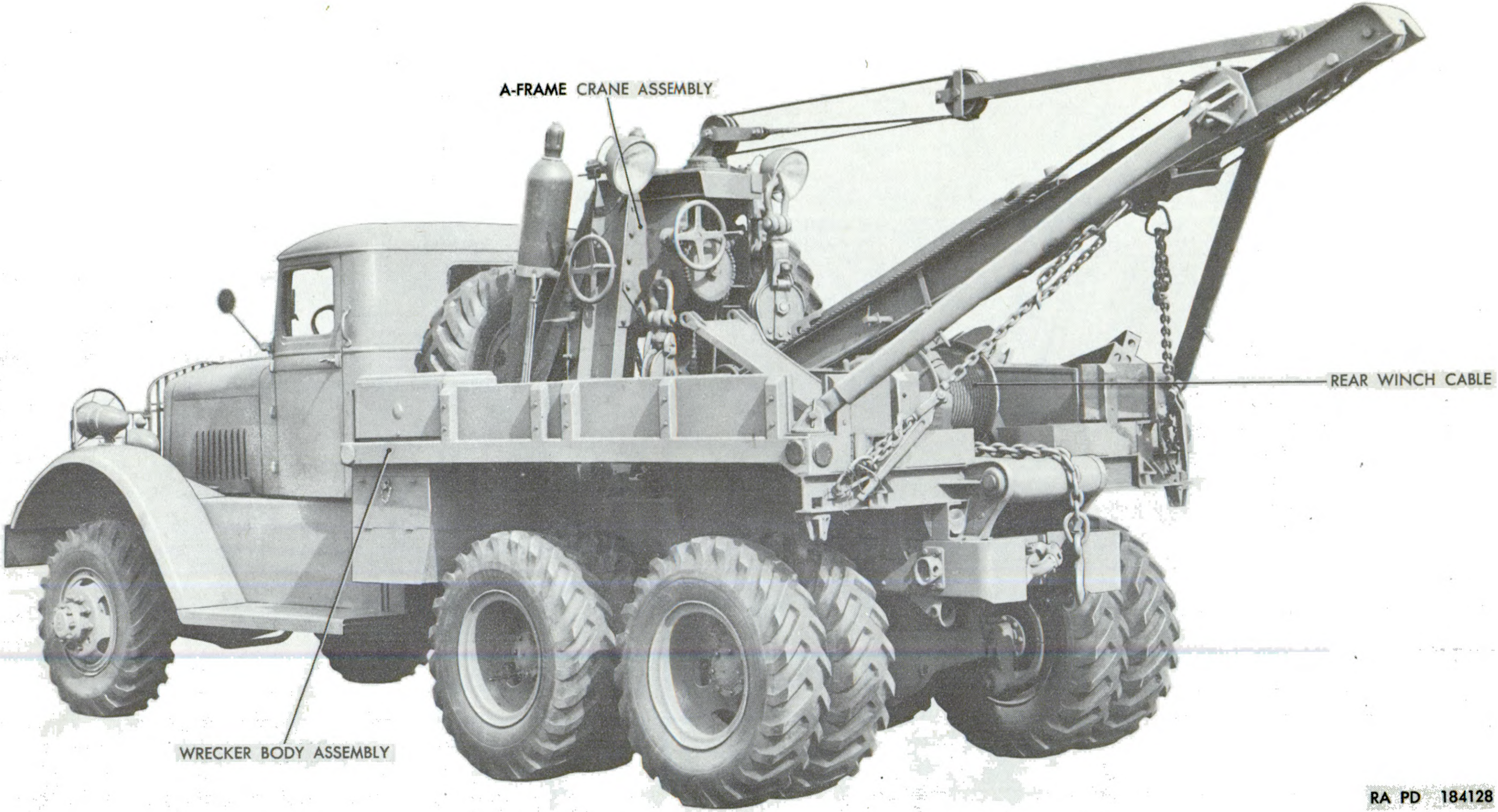

A-FRAME CRANE ASSEMBLY
REAR WINCH CABLE
WRECKER BODY ASSEMBLY
RA PD 184128

Figure 585. Crane assembly on wrecking truck.

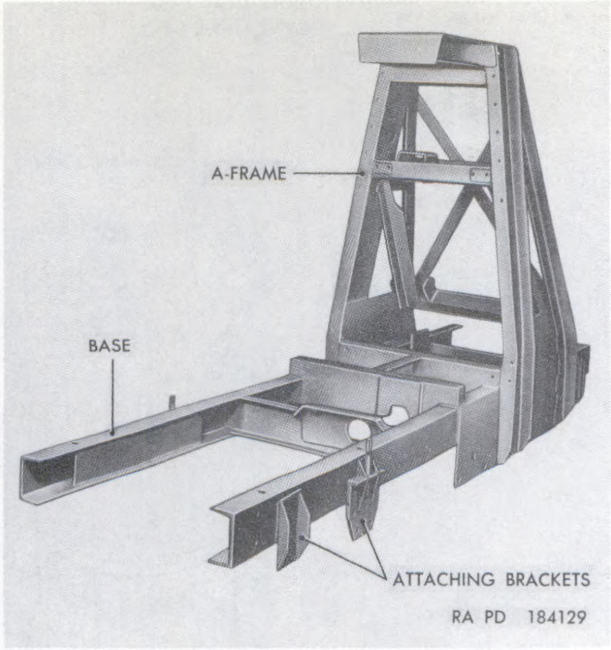


Figure 586. Crane A-frame.

The units include the boom, boom pivot and controls, topping pivot, boom winch and controls, crane winch, crane winch drive and controls, crane winch transmission, and center propeller shaft with connecting parts. All these units are essential to the operation of the crane. There are other units mounted on the **A**-frame which are not part of the crane, including the rear winch, rear winch drive, rear winch transmission, and front-winch jaw clutch.

b. Operation. The various mechanisms incorporated in the crane are driven by the engine through a center propeller shaft. The main drive chain (fig. 587) carries the driving power from the propeller shaft to the hoist gear case, boom gear case, and swinger gear case input sprocket. Each gear case has its own control lever and control system. With these controls, the boom may be raised or lowered, it may be pivoted, and the crane winch can be made to rotate one direction or the other in order to raise or lower the load.

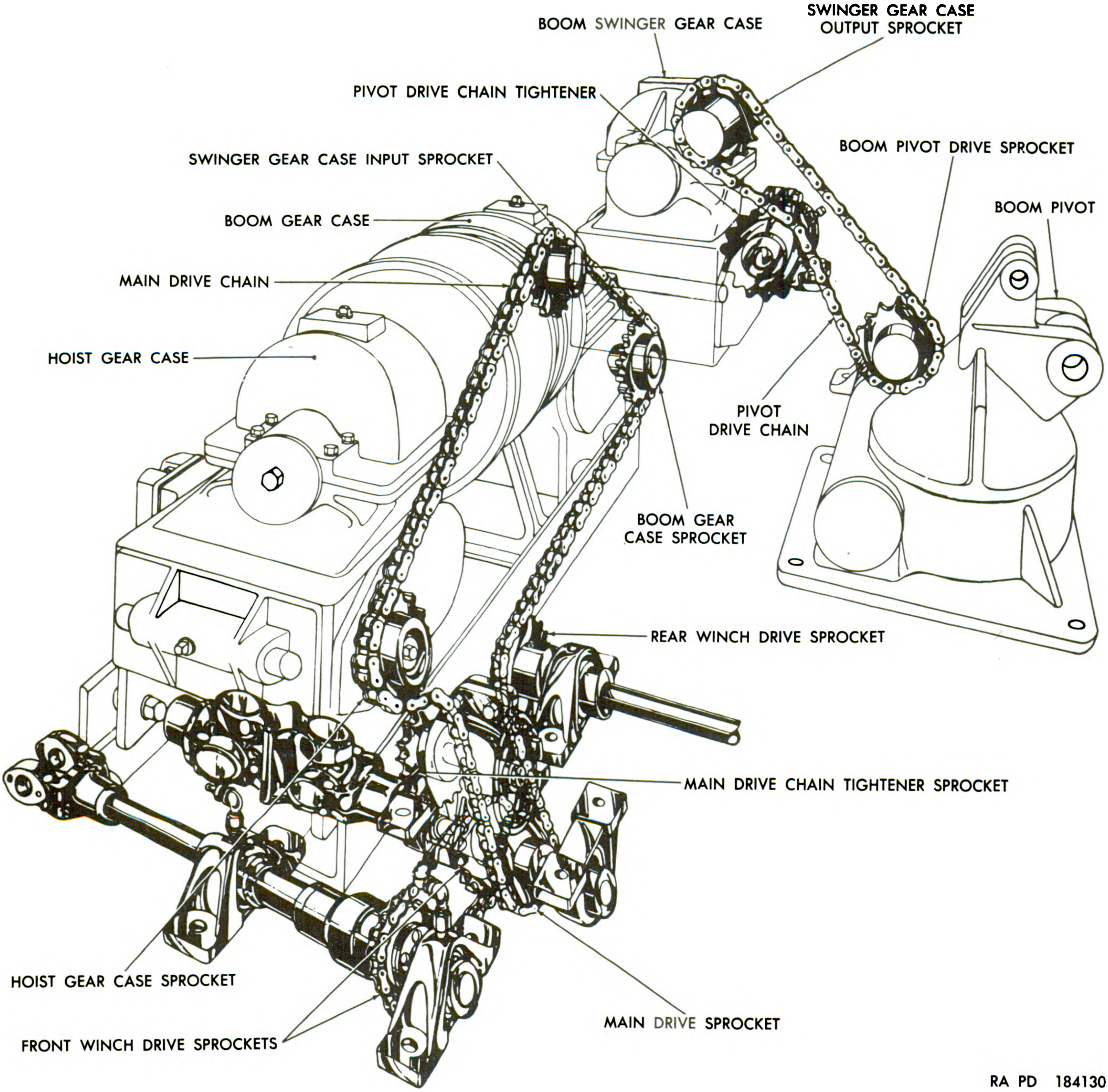

BOOM SWINGER GEAR CASE
SWINGER GEAR CASE OUTPUT SPROCKET
PIVOT DRIVE CHAIN TIGHTENER
SWINGER GEAR CASE INPUT SPROCKET
BOOM PIVOT DRIVE SPROCKET
BOOM PIVOT
BOOM GEAR CASE
MAIN DRIVE CHAIN
HOIST GEAR CASE
PIVOT DRIVE CHAIN
BOOM GEAR CASE SPROCKET
REAR WINCH DRIVE SPROCKET
MAIN DRIVE CHAIN TIGHTENER SPROCKET
HOIST GEAR CASE SPROCKET
FRONT WINCH DRIVE SPROCKETS
MAIN DRIVE SPROCKET
RA PD 184130

Figure 587. Main drive chain and associated parts.

CHAPTER 25

TRAILERS AND SEMITRAILERS

334. General

a. A motor vehicle can pull a heavier load than it can safely carry. This fact is put to use in motor transportation by using trailers and semitrailers. A trailer, or semitrailer, is a cargo vehicle with no motive power of its own, towed by a motor vehicle. Motor vehicles specially designed for towing trailers or semitrailers, are known as *tractors* or *truck tractors.*

b. Considerable time must be spent in loading and unloading certain types of cargoes. Trailers are useful in such cases because they can be left at the loading and unloading points while the tractor tows other loads.

c. Trailer spring suspension is the same as that employed on motor vehicles. Auxiliary springs are often used. Radius rods are usually used to maintain axle alinement and to transmit braking and pulling action between the trailer axle and frame. The wheels are usually slightly cambered.

d. Air, vacuum, or electric braking systems are used with trailers. The trailer braking system is coupled to that of the towing vehicle by a flexible hose and detachable coupling or cables. The trailer braking system is usually designed so that the brakes are applied and keep the trailer in place when these couplings are disconnected. However, when the trailer is detached from the towing vehicle, the trailer brakes will hold for only a limited time. For this reason, wheel blocks are usually used to keep the trailer in place when it is to be idle for some time. Provisions are often made for carrying wheel blocks on a trailer.

e. Trailers are of three general types, depending on the manner in which their weight is supported: The semitrailer, the three-quarter trailer, and the full trailer. A large part of the weight of the semitrailer is supported by its connection (fifth wheel) to the towing vehicle, the remainder being supported by the wheels of the semitrailer. The weight of a three-quarter trailer is mostly balanced on, and supported by, the trailer wheels; and any unbalanced weight is supported by the connection to the towing vehicle. The entire weight of a full trailer is supported by the trailer wheels.

f. Trailers are made in many sizes and are equipped with various body styles, depending on the service for which they are intended. The connections between towing vehicles and trailers differ according to the type of trailer involved. Two main types are used: The fifth wheel (semitrailers), and the pintle hook connection (three-quarter and full trailers).

335. Semitrailers

a. A typical semitrailer chassis (fig. 588) consists mainly of a frame, spring suspension, axle, fifth wheel connection, and a landing gear. It resembles the conventional truck chassis in that its frame is made of two pressed-steel side members with several cross members and has laminated leaf spring suspension. The wheels and tires are interchangeable with those of the tractor used for hauling the trailer. Figure 589 illustrates a semitrailer chassis with tandem axles for carrying heavy trailer loads.

b. Early semitrailer frames were built of straight side members, which meant that the rear of a level trailer body had to be at a considerable height above the ground to clear the rear wheels of the tractor. Such a high frame is objectionable

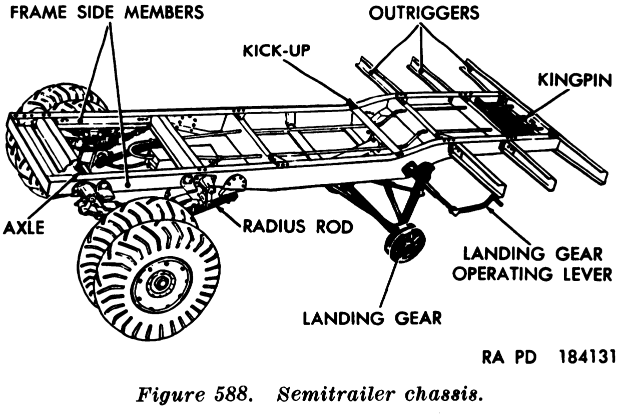


Figure 588. Semitrailer chassis.

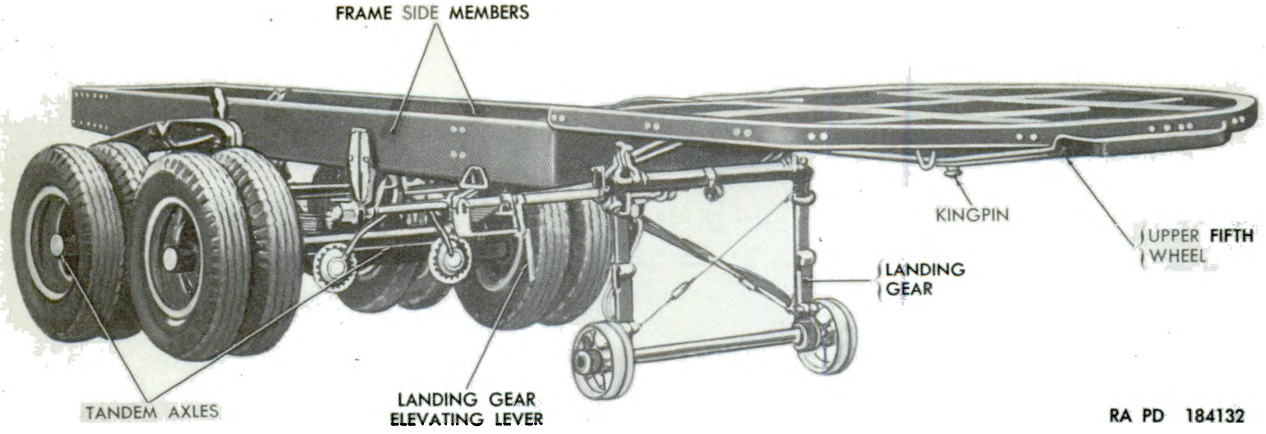


Figure 589. Semitrailer chassis with tandem axles.

because it heightens the center of gravity, making it easier to overturn the trailer. A kickup (fig. 588) in the semitrailer frame permits a lower center of gravity without reducing the necessary clearance space above the rear wheels of the motor vehicle.

c. Cross members are located where the greatest strains occur to the trailer frame. They may be tubular, channel, or box-shaped, with gusset plates riveted or welded to the side members to make a rigid, strong frame.

d. Another type of semitrailer with a variable wheelbase is the "pole" trailer used for transporting long or irregularly shaped goods, such as poles, pipes, or structural members. In this case the pole, or boom, forms the trailer frame. The pole is attached to a turntable mounted on the tractor in much the same manner as a fifth wheel. The trailer axle unit is attached by adjustable clamps to the other end of the pole.

e. A truck-tractor used to haul a semitrailer must be especially designed. Its wheelbase is shorter than that of a standard truck, and the engine and transmission units are designed to produce the necessary power for pulling a loaded semitrailer. Truck-tractors may be designed with the cab over the engine, or may be of conventional truck design, with either single or dual rear axles. The flexible hose connecting the brake system of the tractor to the trailer is clearly shown at the rear of the tractor cab (figs. 590 and 591).

336. Landing Gear

a. The landing gear (fig. 592) is a retractable support under the front end of a semitrailer to hold it up when it is uncoupled from the truck tractor. The two leg members of the landing gear are usually attached to the underside of the trailer chassis by pivot pins. These leg members are connected together by cross braces to resist any side strains. Two small steel wheels, mounted on the end of these leg members, facilitate moving the semitrailer about when it is uncoupled from the tractor. Bracing members connect the lower end of the leg members to a movable bracket containing a nut which rides on a worm shaft located lengthwise between the side members of the trailer frame. Rotation of the worm shaft moves the bracket forward or backward (depending on the direction of rotation) and consequently lowers or raises the landing gear wheels. The landing gear (fig. 592) is shown in its lowered position (semitrailer uncoupled from truck tractor).

b. The worm shaft is supported by bearings in a housing mounted on the underside of the semitrailer chassis. It is rotated by means of a set of bevel gears at the forward end of the housing. These gears are turned by a hand-operated lever at the end of a shaft which extends out to the side of the semitrailer.

c. The height to which the landing gear lifts the front end of the semitrailer above the ground can be varied by adjustable clamps at the top of the two leg members. This adjustment is necessary if the semitrailer is to be used with truck-tractors having different rear end heights.

d. When semitrailers are coupled and uncoupled, it is important that the landing gear be coordinated with the fifth wheel lock. If the landing gear is elevated before the fifth wheel connection is fully locked, the front end of the semitrailer will drop to the ground when the truck-

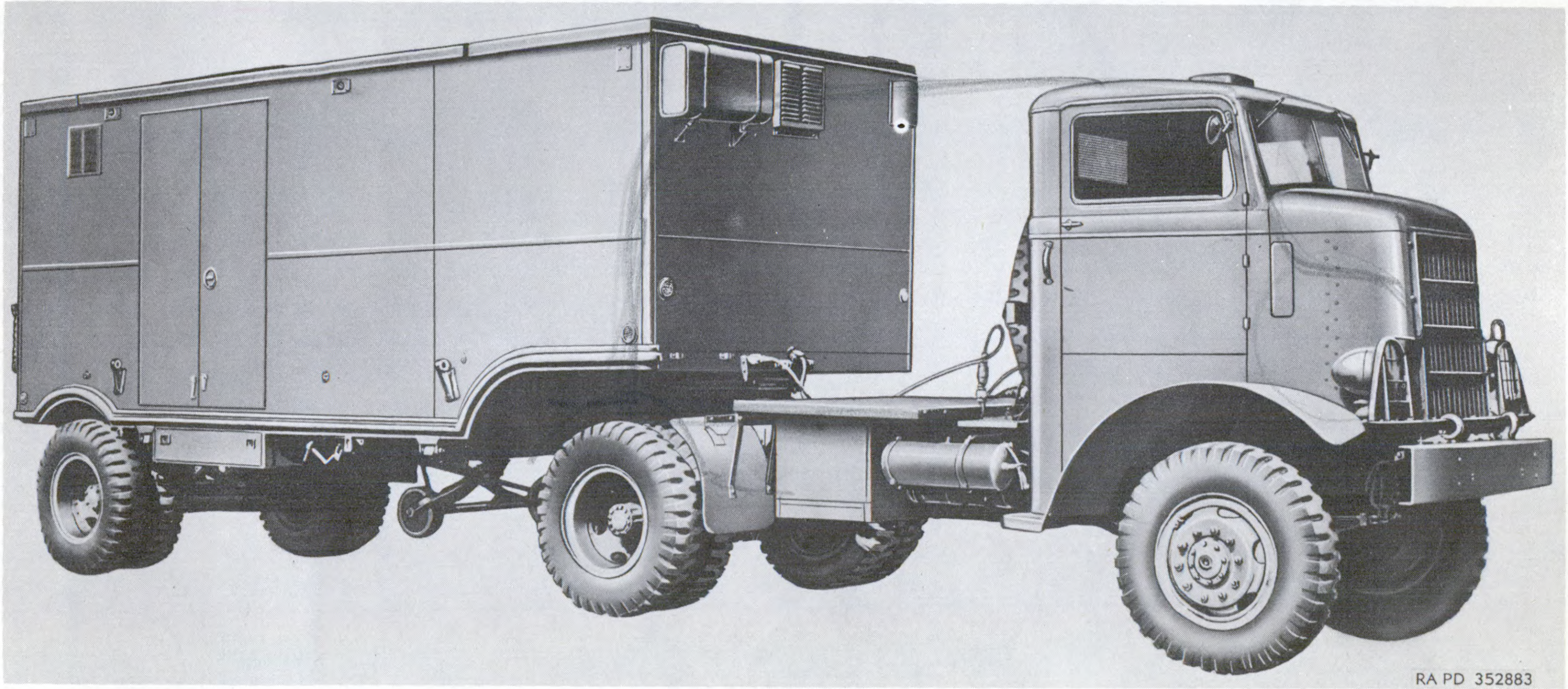
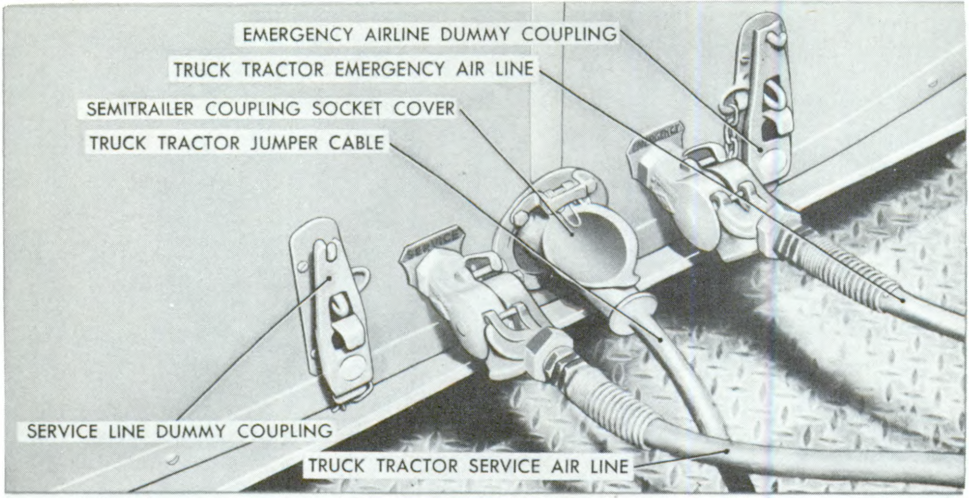
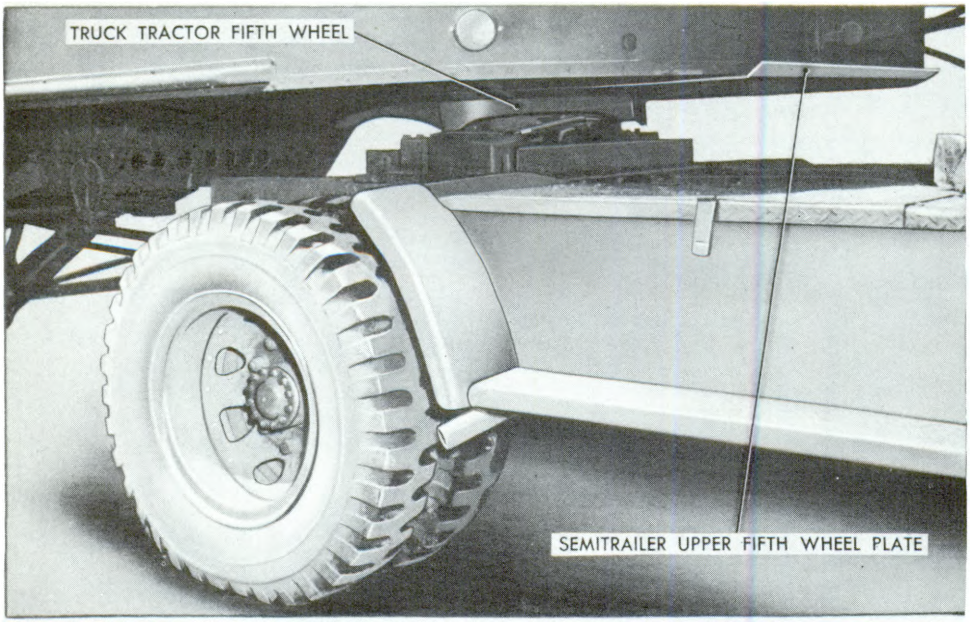

RA PD 352883

Figure 590. Truck-tractor and semitrailer combination.


EMERGENCY AIRLINE DUMMY COUPLING
TRUCK TRACTOR EMERGENCY AIR LINE
SEMITRAILER COUPLING SOCKET COVER
TRUCK TRACTOR JUMPER CABLE
SERVICE
SERVICE LINE DUMMY COUPLING
TRUCK TRACTOR SERVICE AIR LINE

BRAKE LINE COUPLINGS


TRUCK TRACTOR FIFTH WHEEL
SEMITRAILER UPPER FIFTH WHEEL PLATE

FIFTH WHEELS

RA PD 184133

Figure 591. Truck-tractor and semitrailer connections.

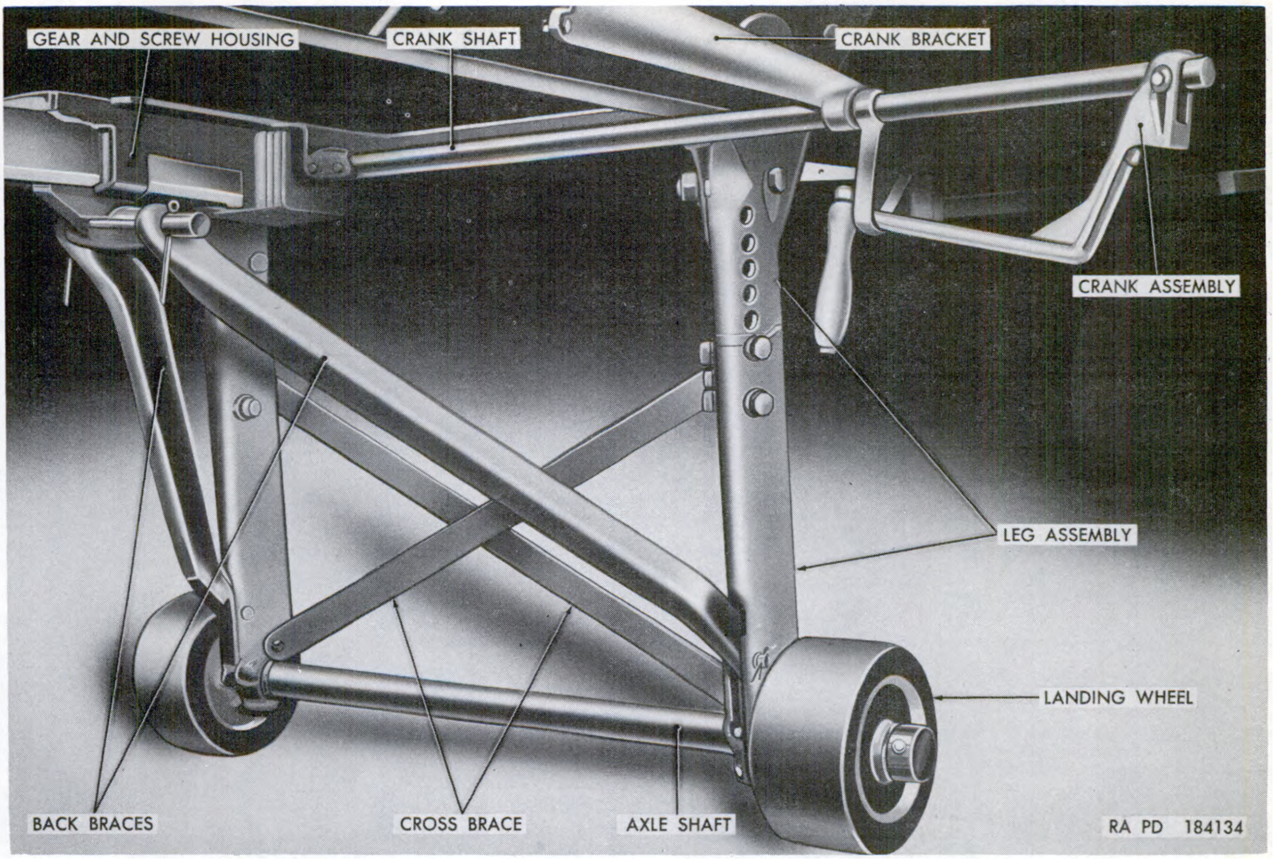


Figure 592. Semitrailer landing gear.

tractor is driven away, with the possibility of damaging both the load and the semitrailer. Before the semitrailer is uncoupled, the brake coupling should be disconnected so that the semitrailer brakes are applied to prevent it from moving. Automatic controls are sometimes used to coordinate the desired features. Auxiliary locking pins strike against the lower fifth wheel plate on the truck-tractor and lock the fifth wheel connection, preventing the trailer from being separated until the landing gear is fully lowered. These auxiliary locking pins are connected by an actuating rod in such a way that they cannot be raised to unlock the fifth wheel connection until the landing gear is fully lowered and the semitrailer brakes are applied.

337. Fifth Wheel

a. The standard method of connecting the truck-tractor to the semitrailer, as mentioned in paragraph 334*e*, is by means of a fifth wheel. A heavy steel plate assembly (fig. 593), known as the *upper fifth wheel plate*, is securely attached to the underside of the front end of the semitrailer frame. This plate serves as the bearing, or front end, support of the semitrailer when it is coupled to a tractor. The front edge of the plate is turned up approximately 45° to form a skid which slides on the lower fifth wheel plate (mounted on the truck-tractor) when the semitrailer is being hitched to the truck-tractor. In the center of the upper fifth wheel plate is a permanently attached kingpin by which the truck-tractor pulls the semitrailer.

b. The lower fifth wheel (fig. 594) contains the movable parts of the fifth wheel assembly and supports the semitrailer load thrust on the truck-tractor. The circular portion of the heavy cast steel plate is the bearing surface upon which the upper plate of the semitrailer rides. The circular groove in the lower plate is a grease retainer for lubricating the rubbing surfaces of the upper and lower plates. The sloping ramps aid in picking up the upper plate of the semitrailer. The wide open space between the ramps guides the kingpin into place. The lower plate is pivoted on

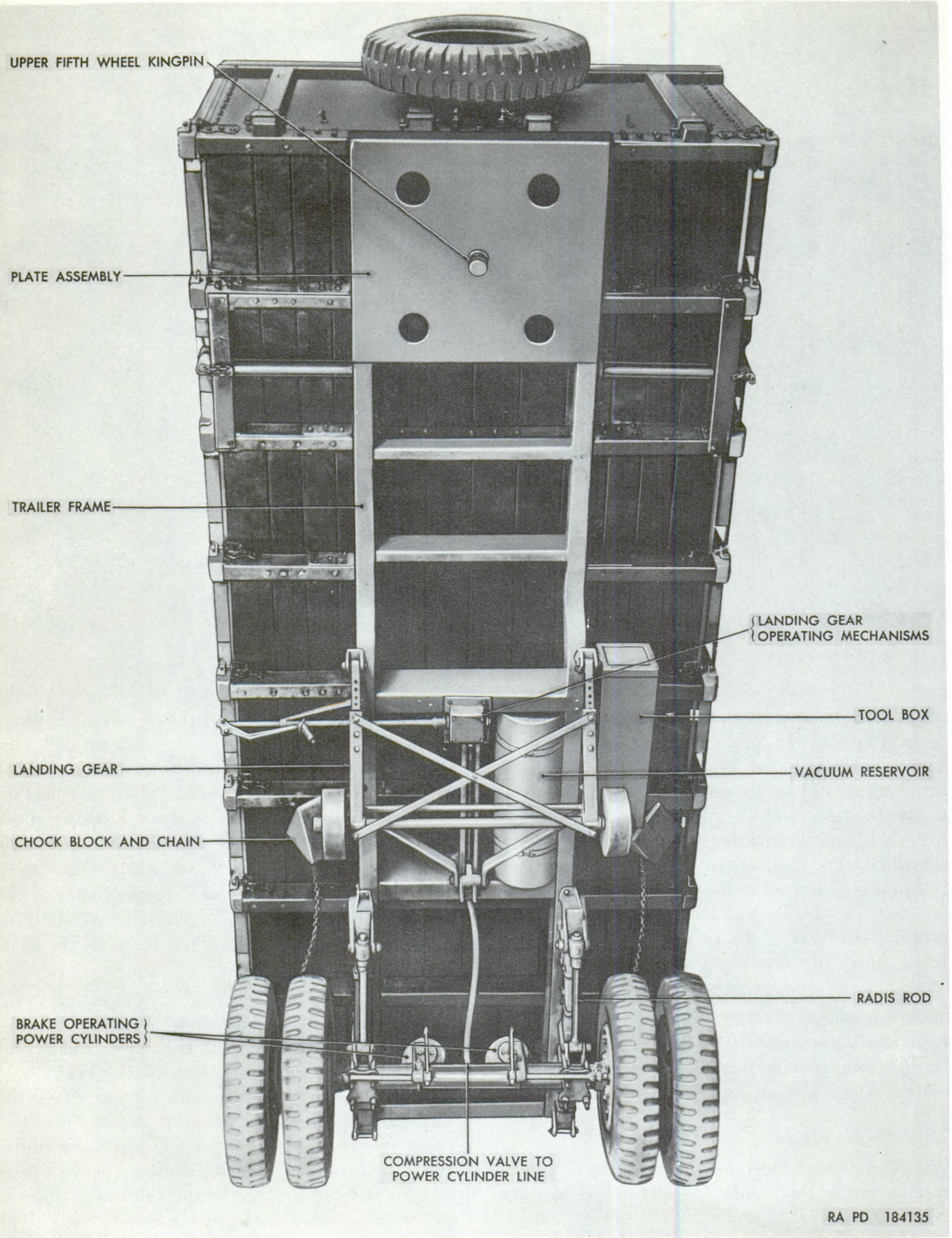

UPPER FIFTH WHEEL KINGPIN
PLATE ASSEMBLY
TRAILER FRAME
LANDING GEAR OPERATING MECHANISMS
TOOL BOX
LANDING GEAR
VACUUM RESERVOIR
CHOCK BLOCK AND CHAIN
RADIS ROD
BRAKE OPERATING POWER CYLINDERS
COMPRESSION VALVE TO POWER CYLINDER LINE
RA PD 184135

Figure 593. Underside of the semitrailer showing upper fifth wheel.

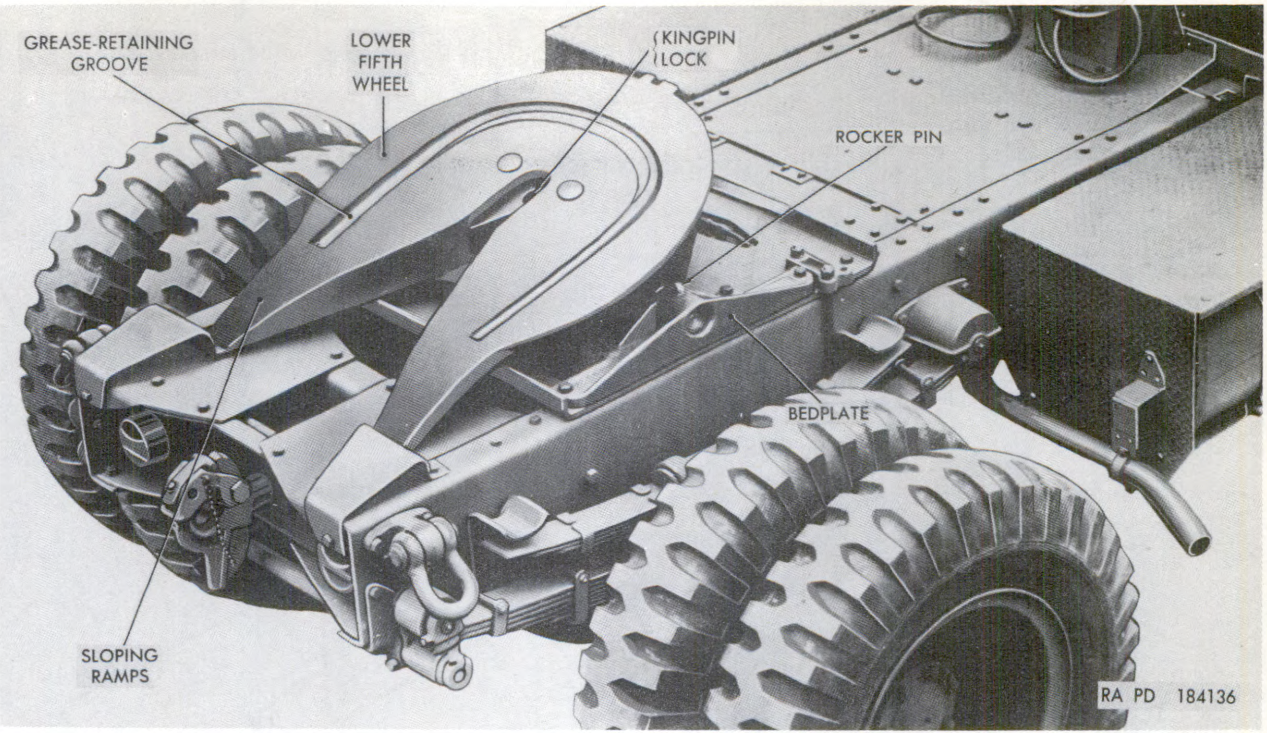


Figure 594. Lower fifth wheel mounted in truck-tractor (semiautomatic coupling).

a rocker pin crosswise to the truck-tractor, providing a free swinging movement between the semitrailer and truck-tractor. The outer ends of the rocker pin are supported in pillow blocks bolted to a bedplate which is mounted on the frame of the truck-tractor.

c. There are three types of fifth wheel couplings: permanent, semiautomatic, and automatic. In a permanent fifth wheel coupling, the kingpin is made part of the lower fifth wheel plate, and, once it is locked in position, the truck-tractor is operated with the same semitrailer at all times. In semiautomatic and automatic fifth wheel couplings, the kingpin is contained on the upper fifth wheel plate. The kingpin is locked in position by a kingpin lock which is a ring on the lower fifth wheel that clamps around the kingpin. In the semiautomatic coupling, which is the most popular type, the kingpin lock (fig. 594) is operated by a hand lever that extends to the side of the lower fifth wheel. The automatic coupling is locked in a similar manner, except that it is controlled by the operator from the truck-tractor cab.

338. Load Distribution

a. The fifth wheel should be located at a point on the truck-tractor chassis that will best distribute the portion of the semitrailer load thrust on the truck-tractor. The ideal load distribution for a truck-tractor and semitrailer combination is illustrated in figure 595. The fifth wheel should be well ahead of the tractor rear axle to accomplish this.

b. Another important factor in the location of the fifth wheel is that of safety in hilly or mountainous country. When climbing hills, the load thrust will act at a point back of the truck-tractor rear wheels, as shown in upper diagram in figure 596, if the fifth wheel is located directly over the rear wheels, and will tend to raise the front wheels of the truck-tractor off the road. This will cause a dangerous loss of steering control, which is aggravated by each bump in the road. With the fifth wheel and, consequently, the load center located well ahead of the rear wheels, this hazard is avoided, as the load thrust will always fall ahead of the driving axle, as shown in lower diagram in figure 596.

c. Another danger from an incorrectly located fifth wheel is created by the momentum of the semitrailer. The momentum of the semitrailer has a tendency to push the rear end of the truck-tractor off the road when on a sharp turn (jackknifing), especially if the road is wet or covered with ice or

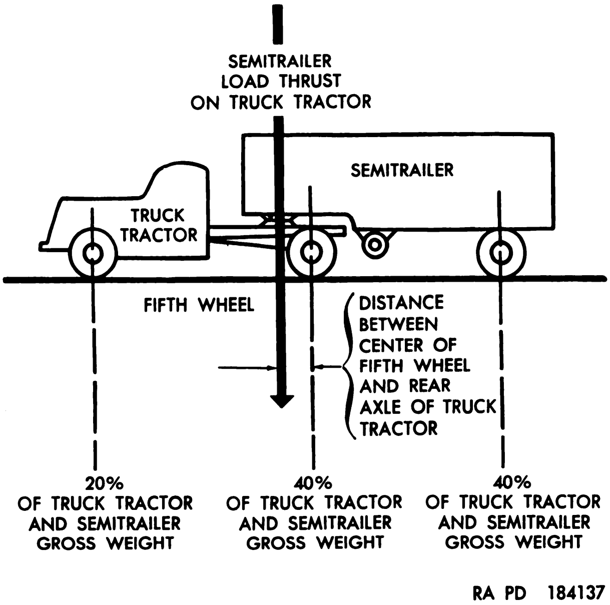

SEMITRAILER
LOAD THRUST
ON TRUCK TRACTOR
SEMITRAILER
TRUCK
TRACTOR
FIFTH WHEEL
DISTANCE
BETWEEN
CENTER OF
FIFTH WHEEL
AND REAR
AXLE OF TRUCK
TRACTOR
20%
OF TRUCK TRACTOR
AND SEMITRAILER
GROSS WEIGHT
40%
OF TRUCK TRACTOR
AND SEMITRAILER
GROSS WEIGHT
40%
OF TRUCK TRACTOR
AND SEMITRAILER
GROSS WEIGHT
RA PD 184137

Figure 595. Ideal local distribution for truck-tractor and semitrailer combination.

snow. With the fifth wheel located well ahead of the truck-tractor rear wheels, the load thrust is placed between the truck-tractor axles and offers additional resistance to the momentum of the semitrailer when it tends to jackknife.

d. Clearance of at least one foot between the rear of the truck-tractor cab and the front of the semitrailer body should always be maintained.

339. Three-Quarter Trailers

a. Three-quarter trailers (usually 2-wheel) are used for light loads. The entire trailer load is practically balanced on the trailer suspension. Usually about 15 percent of the trailer load is thrust on the tractor connection. Three-quarter trailers are built in many sizes and are fitted with various forms of bodies ranging from the general pickup and tank (fuel and water) to the more elaborate house trailers used as hospital and recruiting vehicles. In some of the heavier types, tandem axles are employed to carry the load.

b. Three different types of three-quarter trailers are illustrated in figures 597 through 599. The frame and body form an integral unit. The cross members underneath the body reinforce the floor board and form the rear section of the frame. The front end of the trailer body rests directly on a V-frame.

c. The landing gear wheel rotates on a shaft held by a yoke which is free to turn horizontally. The yoke is also pivoted to a landing gear casting so

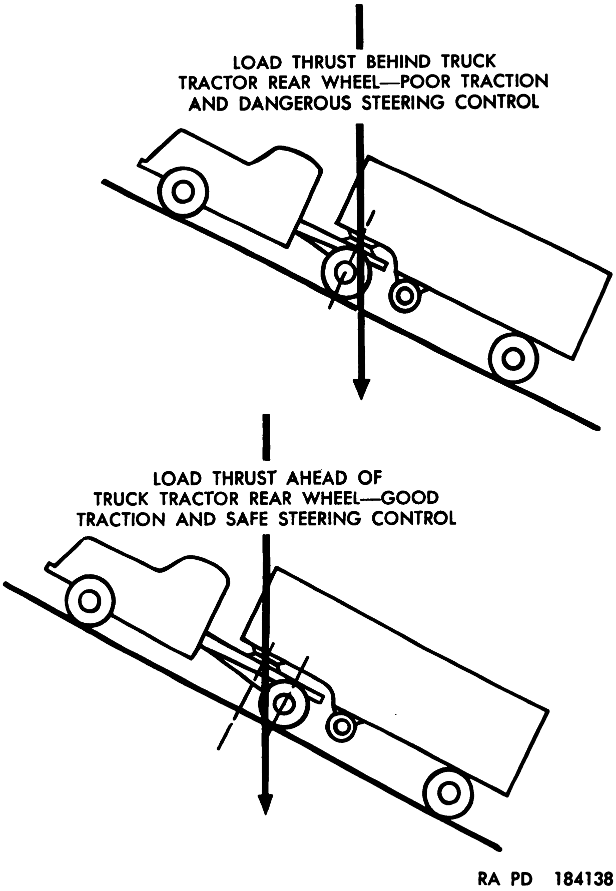

LOAD THRUST BEHIND TRUCK
TRACTOR REAR WHEEL—POOR TRACTION
AND DANGEROUS STEERING CONTROL
LOAD THRUST AHEAD OF
TRUCK TRACTOR REAR WHEEL—GOOD
TRACTION AND SAFE STEERING CONTROL
RA PD 184138

Figure 596. Effect of fifth wheel location when climbing hills.

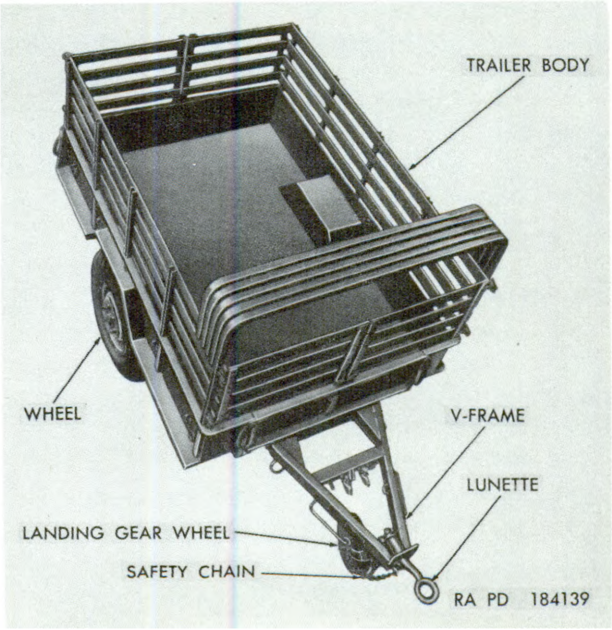

TRAILER BODY
WHEEL
V-FRAME
LUNETTE
LANDING GEAR WHEEL
SAFETY CHAIN
RA PD 184139

Figure 597. Two-wheel cargo trailer.

that the wheel may be raised or lowered. A removable pin can be placed in various holes of the yoke to hold the wheel at the desired height. The lunette (fig. 600) (towing hook), mounted on top of the landing gear, is connected to the pintle assembly of the towing vehicle. A short safety chain connects the trailer and the towing vehicle to prevent the trailer from breaking loose. A tail lamp cable connects the trailer tail lamp to the electrical system of the towing vehicle. A simple mechanical parking brake is used when the

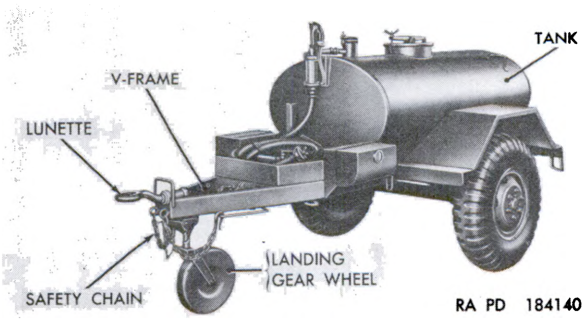

TANK
V-FRAME
LUNETTE
LANDING GEAR WHEEL
SAFETY CHAIN
RA PD 184140

Figure 598. 1-ton 2-wheel water tank trailer.

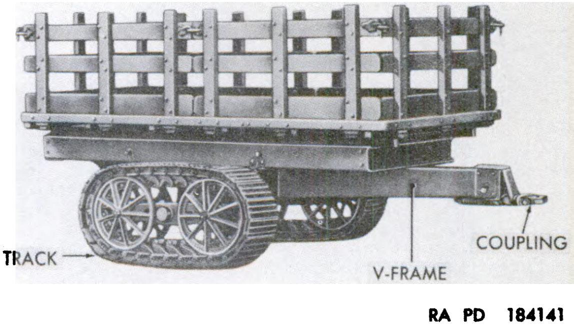

TRACK
COUPLING
V-FRAME
RA PD 184141

Figure 599. Tracked trailer.

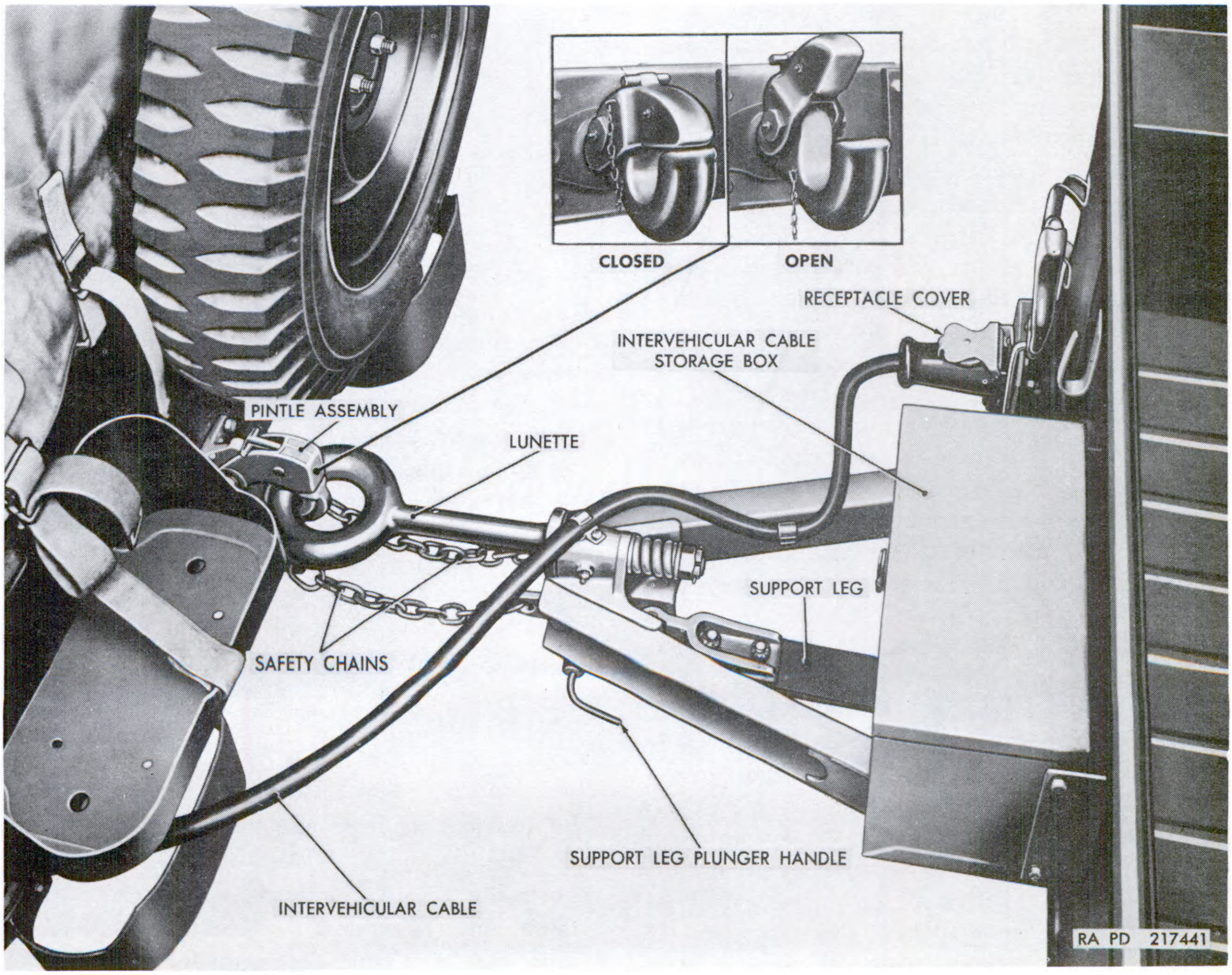

CLOSED
OPEN
RECEPTACLE COVER
INTERVEHICULAR CABLE STORAGE BOX
PINTLE ASSEMBLY
LUNETTE
SUPPORT LEG
SAFETY CHAINS
SUPPORT LEG PLUNGER HANDLE
INTERVEHICULAR CABLE
RA PD 217441

Figure 600. Pintle assembly connection to a 1-ton 2-wheel trailer.

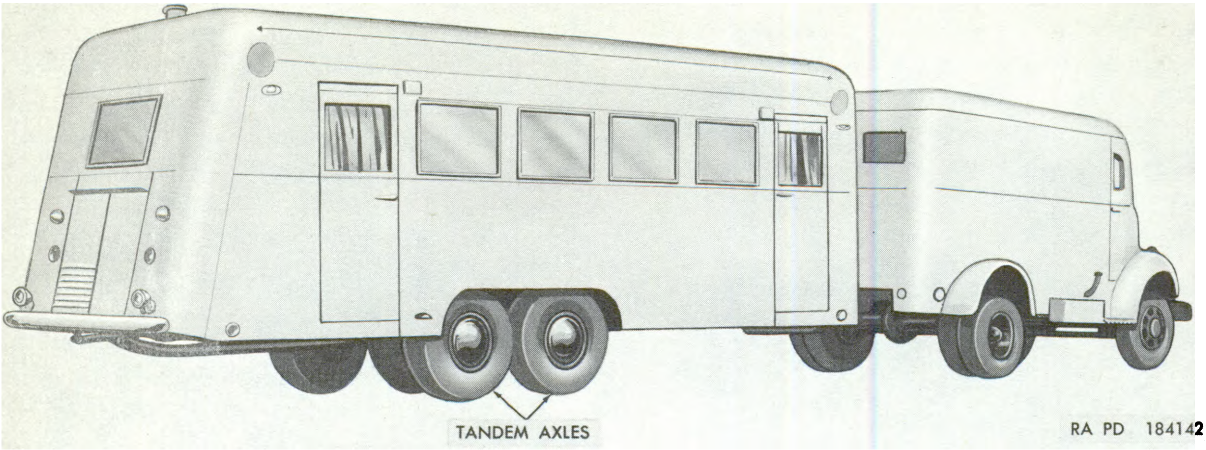


Figure 601. House trailer with tandem axles.

trailer is uncoupled from the motor vehicle. It is operated by a hand lever.

d. A house trailer equipped with tandem axles is illustrated in figure 601. It is hitched to the towing vehicle by a standard SAE No. 2 ball-and-socket coupler (fig. 602). Its landing gear consists of an upright worm shaft with a small caster wheel clamped to its bottom end. When the trailer is being towed, the caster wheel is removed by loosening a thumbscrew and the worm shaft raised by a hand crank.

e. Safety towing chains are connected between the trailer and the towing vehicle. Another safety feature is the short chain fastened by a snaphook to the towing vehicle and by an open-loop spring hook which fits around a pin on the trailer brake safety switch. If the trailer breaks loose, the towing vehicle will jerk the chain away from the pin, which is thereby released to operate the switch that immediately applies the brakes of the trailer. An electrical lead connects the trailer brakes to the electrical brake connection on the towing vehicle.

f. Six screw jacks are used for supports when the trailer is parked. These jacks are placed underneath the frame on both sides at the front, center, and rear and permit the trailer to be leveled and its load to be supported when parked.

g. House trailers, in comparison to other types of trailers, are lightly built to reduce weight and to allow the use of soft springs. They are usually designed for use with soft spring passenger vehicles. If they are coupled to vehicles with stiff springs, the towing connection will be jarred considerably.

340. Full Trailers

a. Full trailers, which support their entire load, may be connected directly behind the towing vehicle, to a semitrailer, or to another full trailer. They are independent and fully contained vehicles without motive power.

b. Early full trailers were equipped with knuckle or Ackerman steering used on motor vehicles, but all full trailers now use fifth wheel steering. Many full trailers are constructed with a simple type of fifth wheel consisting of two large steel plates and a kingpin. In a heavily loaded trailer, considerable binding between the fifth wheel plates hinders free steering, so when the driver steers the motor vehicle to the right or left, the binding fifth wheel resists the turning effort and tends to keep the motor vehicle traveling straightahead. This is readily apparent to the driver when operating on slippery roads and makes steering not only difficult, but dangerous. To overcome this, there is a tendency toward more refined fifth wheel designs that will turn freely under heavy loads by the use of bearings.

c. Full trailers may be classified as nonreversible, reversible, and converted semitrailers. A nonreversible full trailer can be towed and steered from one end only. Its frame is supported by front and rear 2-wheel trucks which consist of a square frame made of channel sections containing the spring hangers. The rear truck is bolted to the trailer frame and forms an integral part of the chassis. A lower fifth wheel ring mounted on top of the front truck fits together with an upper fifth wheel ring attached underneath the front

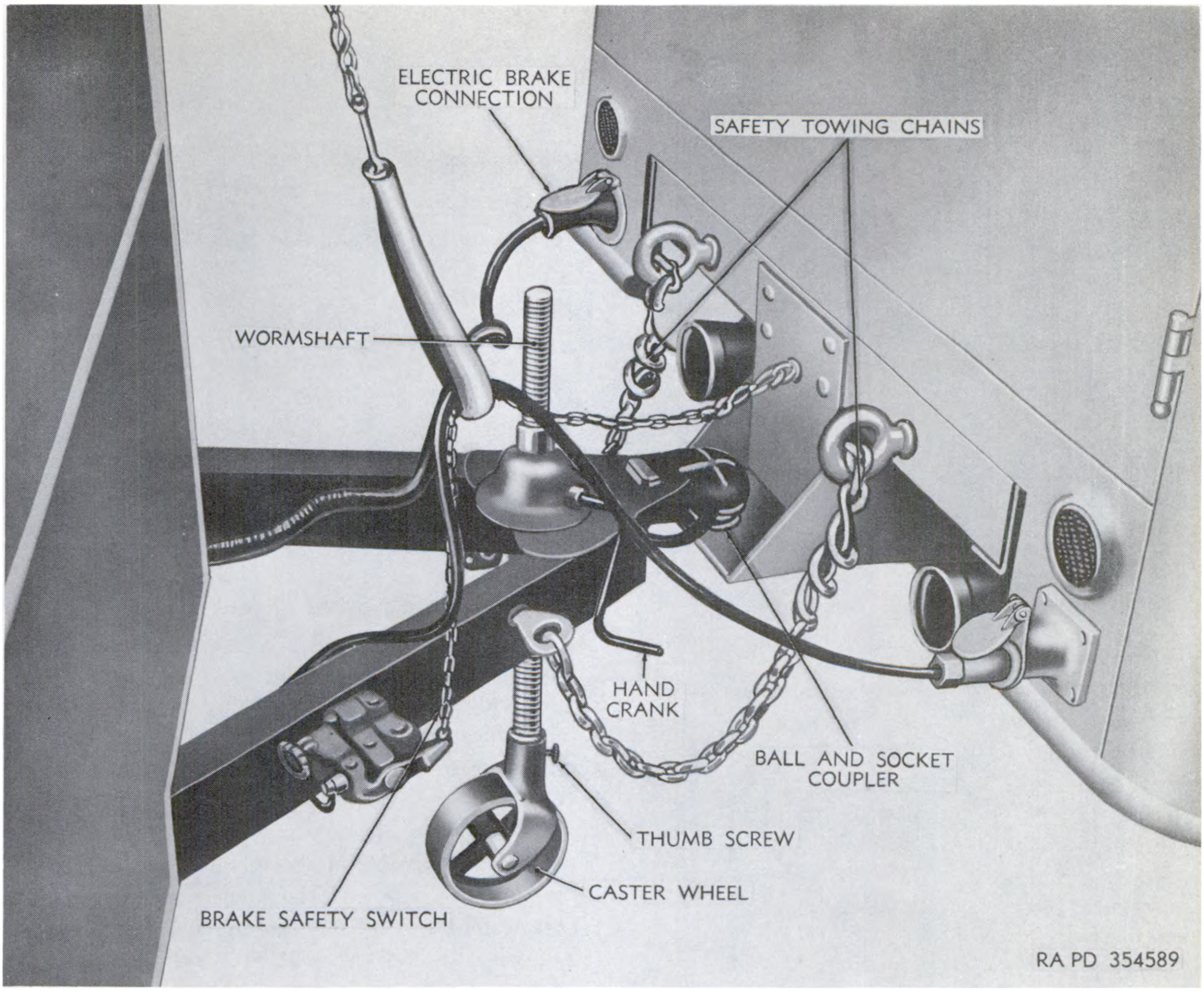


Figure 602. Ball-and-socket connection to a house trailer.

end of the trailer frame. The front truck, therefore, turns about the fifth wheel, which allows the trailer to be steered. A towing tongue is pivoted to the front truck, and the other end contains a lunette which connects with the pintle hook of the towing vehicle. The trailer chassis illustrated in figure 603 is equipped with electrical and air brake connections which are hooked up to the towing vehicle. A safety chain is provided to prevent the trailer from running away if the pintle hook connection should break loose.

d. A reversible full trailer may be towed or steered from either end. It is similar to the nonreversible trailer in construction and appearance, except that both front and rear trucks are mounted by fifth wheels. The towing tongue is detachable and may be used with either truck. Both trucks are provided with locks so that one may be prevented from turning when the other is connected to the towing ends, thus increasing the operating flexibility of the trailer.

e. A semitrailer may be converted into a full trailer by mounting the fifth wheel on a dolly (fig. 604) and using the dolly in place of a tractor as the semitrailer front end support. Such a combination is known as a *converted semitrailer*. The dolly is merely a short 2-wheel trailer chassis with a standard lower fifth wheel mounted on its frame. The front end of its frame is tapered to receive a bracket that contains a lunette for towing the trailer by a pintle assembly. A retractable landing gear supports the front end of the dolly when not in use. The open hooks on either side at the front end of the frame are used for joining the towing vehicle and the trailer with safety chains.

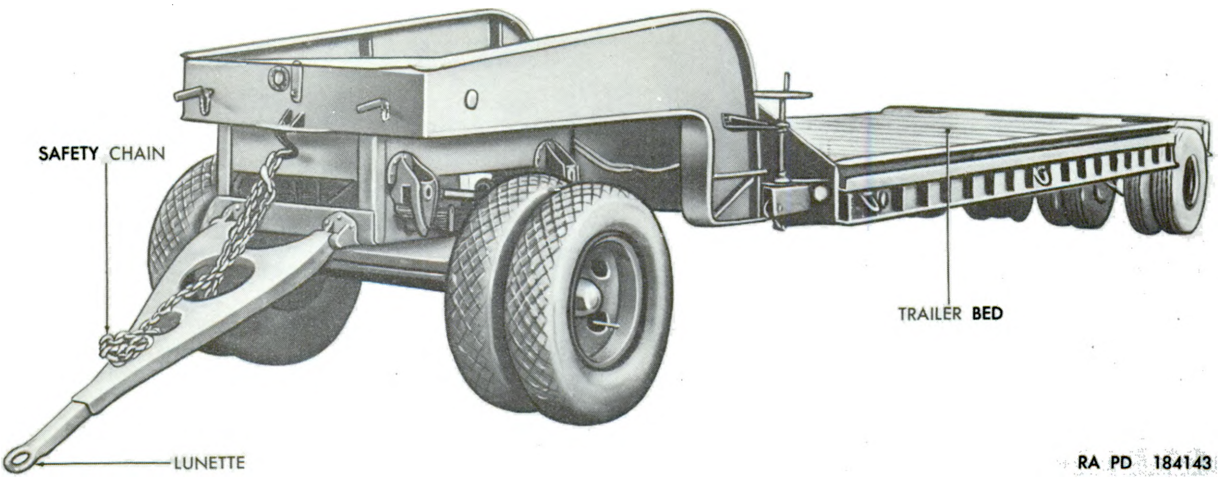


Figure 603. Nonreversible, low-bed, full trailer.

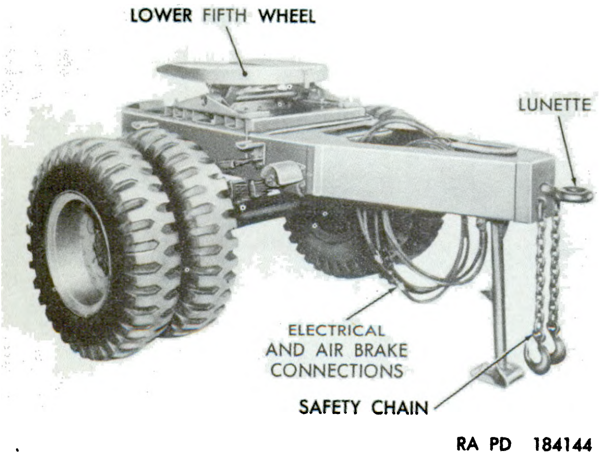


Figure 604. Dolly for converting a semitrailer to a full trailer.

f. The rear end view of a heavy-duty vehicle (fig. 605), used for towing three-quarter and full trailers, illustrates the pintle assembly. The rear bumpers protect the frame of the vehicle and guide the trailer lunette (towing hook) into the pintle assembly during the trailer coupling operation. The electric brake lead of the trailer is plugged into the electric brake connection, shown with the cover open. The air brake connections enable the air braking system of the towing vehicle to be joined to that of the trailer when the trailer is equipped with air brakes. The air brake connection is shown with its cap removed as it would appear when ready for coupling.

341. Matching Towing Vehicle and Trailer

a. General. Matching a towing vehicle and a trailer means more than merely coupling them up. The brake systems must match, as well as the electrical systems. Furthermore, the trailer load must not exceed the performance of the towing vehicle.

b. Matching Electrical Systems. The towing vehicle and trailer electrical systems must be of the same voltage. If the towing vehicle has a 6-volt system, the trailer must have a 6-volt system. Likewise, if one has a 12-volt system, the other must have a 12-volt system. Connecting 6-volt lights into a 12-volt system will cause them to burn out as soon as they are turned on. On the other hand, 12-volt lights connected to a 6-volt source will give little or no light.

c. Matching Brake Systems. The brake systems must also match. If the towing vehicle has an air-pressure brake system, the trailer must also have an air-pressure brake system. Likewise, if the towing vehicle has a vacuum-type or an electric braking system, the trailer must have a matching braking system.

d. Matching Load and Performance. To avoid overloading the towing vehicle, excessive loads must not be hitched to it. The trailer load must not be above that which the towing vehicle was designed to pull. The technical manual of the towing vehicle usually has the maximum trailer load listed in the tabulated data section. If it does not, the drawbar pull can be calculated as explained in paragraph 232.

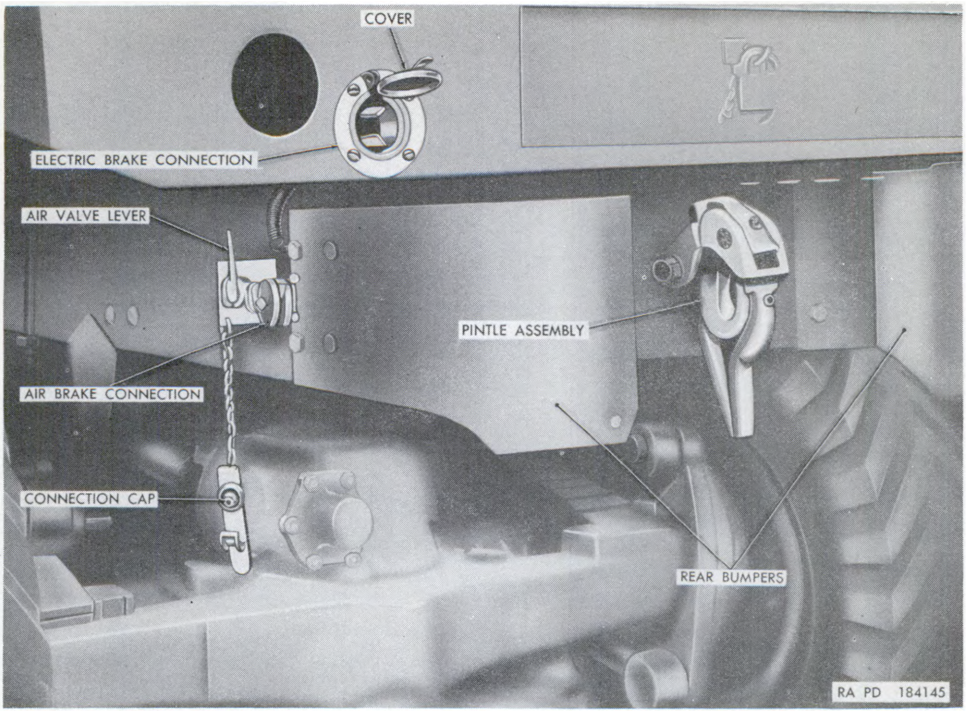

COVER
ELECTRIC BRAKE CONNECTION
AIR VALVE LEVER
PINTLE ASSEMBLY
AIR BRAKE CONNECTION
CONNECTION CAP
REAR BUMPERS
RA PD 184145

Figure 605. Vehicle used for towing three-quarter and full trailers—rear end view.

PART SEVEN
MOTORCYCLES AND SCOOTERS
CHAPTER 26
MOTORCYCLES

Section I. INTRODUCTION

342. Types

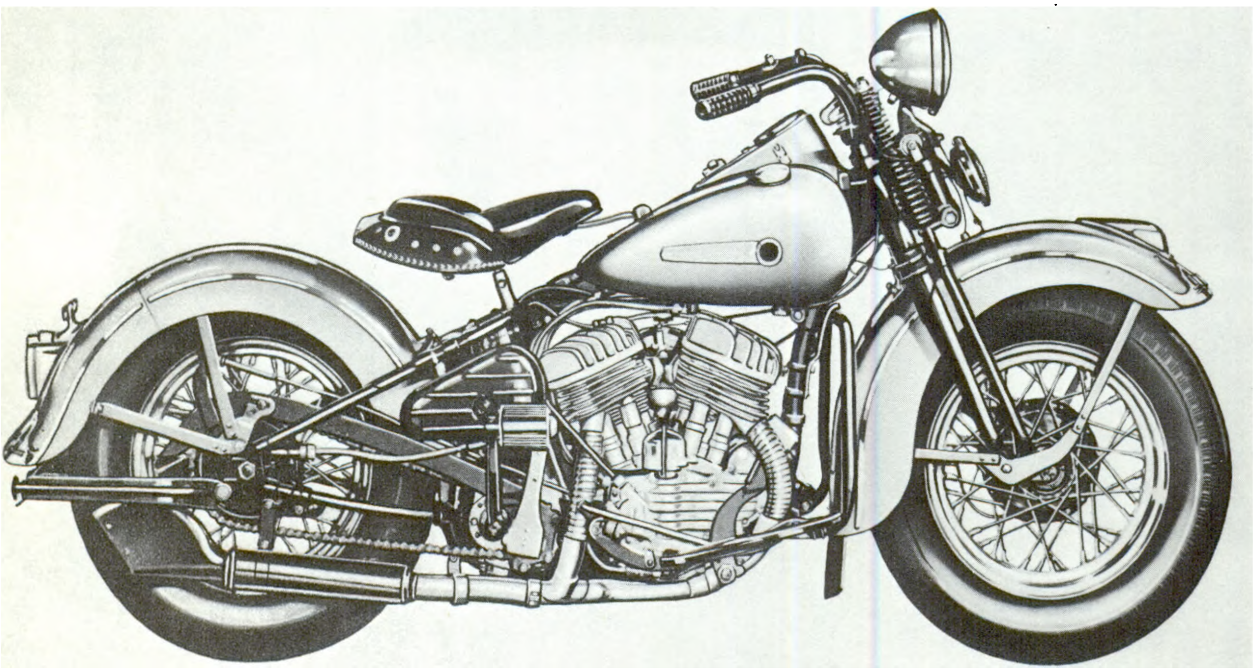
a. The solo motorcycle (fig. 606), motorcycle with sidecar (fig. 607), and motor tricycle (fig. 608) are three variations of the motorcycle. This manual covers only the solo motorcycle, since the other two types are very similar in construction and operation.

b. Motorcycles are also classified as to type of drive. They may be either chain-driven, which is the most common type, or shaft-driven. Power from the engine is transmitted to the rear wheels by a chain or propeller shaft with universal joints similar to those used on cars and trucks. The chain-driven type only is covered herein, since the standard military motorcycle is of this type.

343. Construction

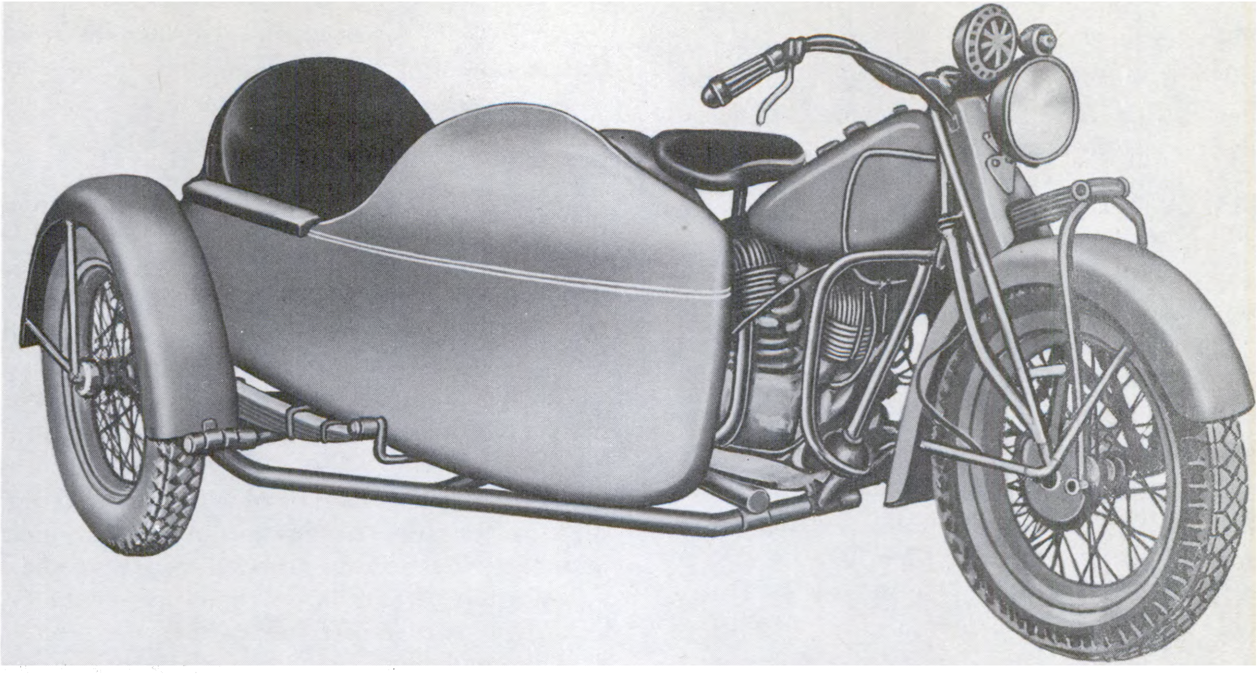
a. The solo motorcycle (fig. 606) is similar in appearance to a bicycle. The two wheels are mounted in a tubular frame which supports the various components of the motorcycle, the front wheel being steered by a handlebar.

b. Power is developed by an air-cooled, 2-cylinder, 4-stroke cycle, internal combustion engine, and is transmitted to the rear wheel through a clutch, transmission, and chain- or shaft-driven final drive. The clutch and transmission perform the same functions as in other motor vehicles.



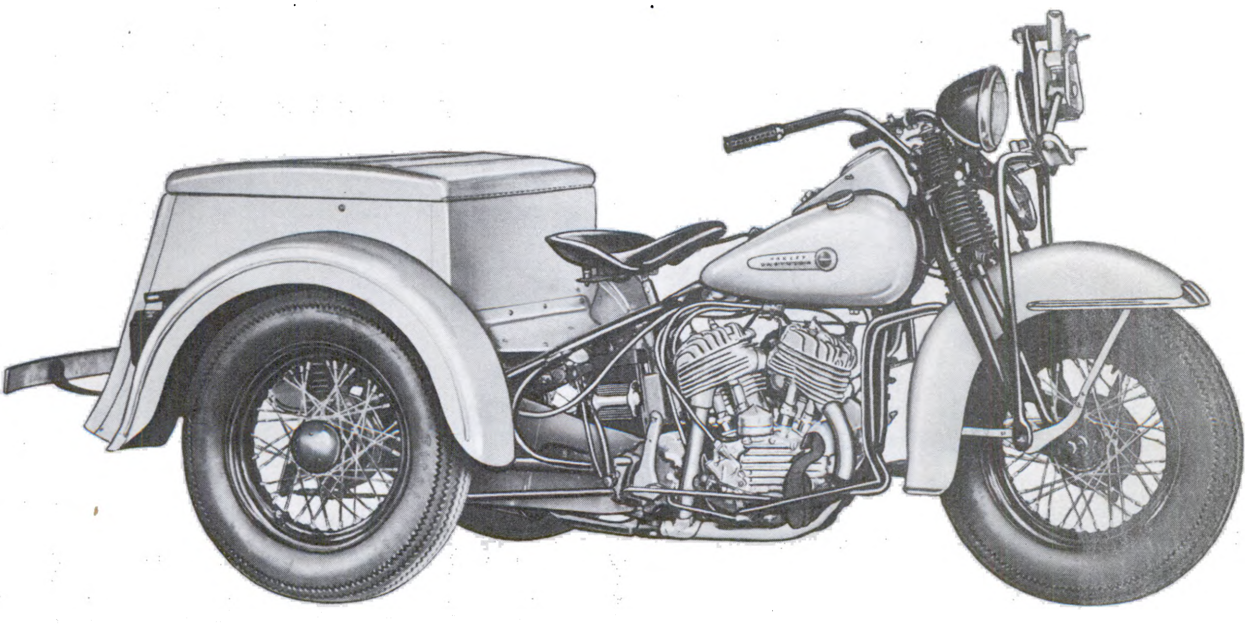
RA PD 184146

Figure 606. Solo motorcycle.



RA PD 184147

Figure 607. Motorcycle with sidecar.



RA PD 184148

Figure 608. Motor tricycle.

Section II. CHASSIS

344. General

The motorcycle chassis consists of the wheels, frame, front suspension, steering mechanism, saddle and seat post, and brakes.

345. Wheels

a. Wire wheels (par. 247) with drop-center-type rims (par. 253) and conventional tires (par. 248) are used on motorcycles.

b. Motorcycle wheel axles are generally of the knockabout type. Plain roller bearing, tapered roller bearing, ball bearing, or combination ball and roller bearing hubs are installed in the front and rear wheels (figs. 609 through 612). Plain roller bearing hubs are adjusted for end play by means of shims. Oversized bearings are used for excessive radial play. Tapered roller bearing hubs require no end play adjustment. Ball bearing hubs are adjustable for end play by means of movable adjusting cones.

346. Frames

a. Motorcycle frames are constructed of steel forgings, castings, and tubing welded or brazed together. A steering head is provided at the front end to support the front wheel fork. The rear wheel is secured to the rear frame fork. The engine is mounted on the bottom loops, or between the open ends of the open-loop frame.

b. Single- and double-loop frames (figs. 613 and 614) are rigid and complete in themselves, the difference between them being in the single- or double-tube lower members. The open-loop, or keystone, frame (fig. 615) is not a complete, rigid structure. The engine with this frame is mounted in the opening of the loop and the engine crankcase, or rigid side plates, complete the loop to form a rigid support.

c. A variation of the double-loop frame (fig. 616) contains coil springs mounted in the rear wheel fork to absorb road shocks. The rear wheel axle fits into the brackets on the slipper cylinders, or spring housings. The slipper cylinder is set at a slight angle to allow the rear wheel to move up and down without stretching the final-drive chain. The load, or lower, springs carry the weight of the motorcycle, while the recoil, or upper, springs check the rear wheel rebound and absorb the road shocks.

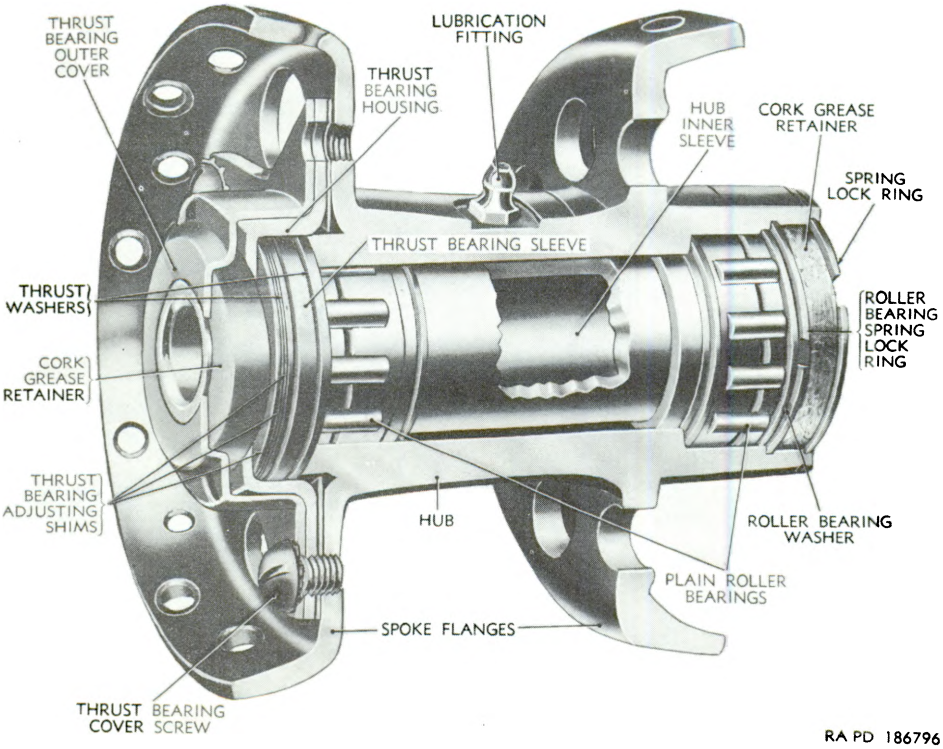

THRUST BEARING OUTER COVER
LUBRICATION FITTING
THRUST BEARING HOUSING
HUB INNER SLEEVE
CORK GREASE RETAINER
SPRING LOCK RING
THRUST BEARING SLEEVE
THRUST WASHERS
ROLLER BEARING SPRING LOCK RING
CORK GREASE RETAINER
THRUST BEARING ADJUSTING SHIMS
HUB
ROLLER BEARING WASHER
PLAIN ROLLER BEARINGS
SPOKE FLANGES
THRUST BEARING COVER SCREW
RA PD 186796

Figure 609. Plain roller bearing type hub.

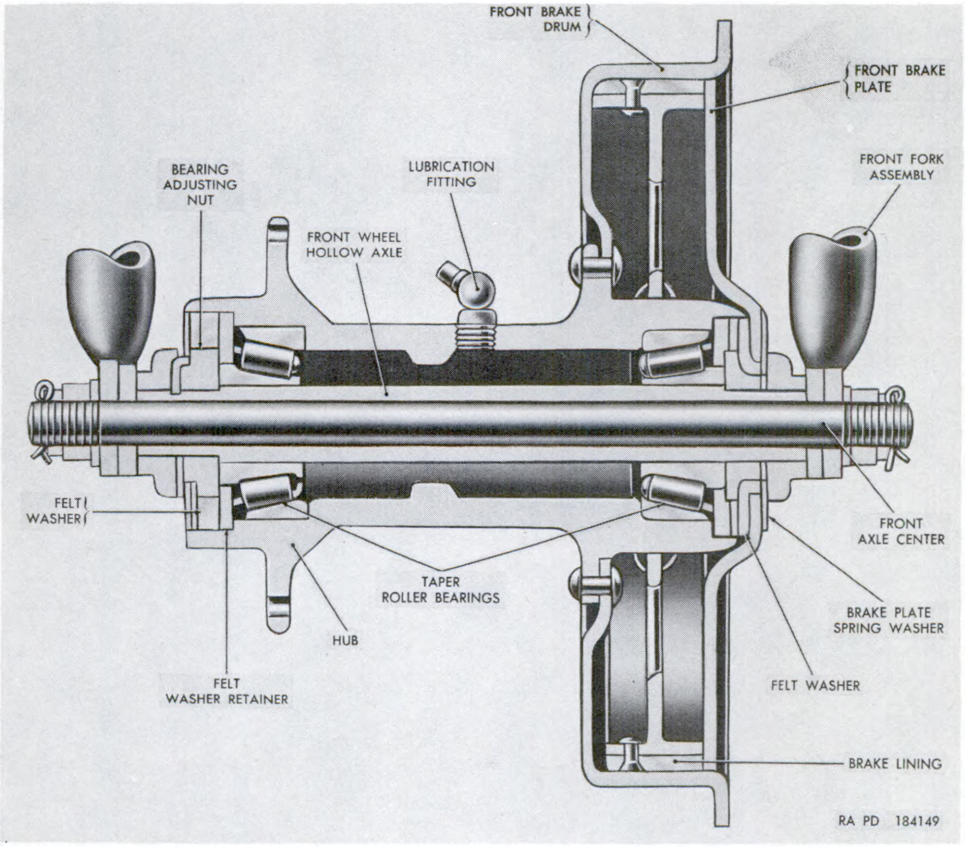

FRONT BRAKE DRUM
FRONT BRAKE PLATE
BEARING ADJUSTING NUT
LUBRICATION FITTING
FRONT FORK ASSEMBLY
FRONT WHEEL HOLLOW AXLE
FELT WASHER
FRONT AXLE CENTER
TAPER ROLLER BEARINGS
BRAKE PLATE SPRING WASHER
HUB
FELT WASHER
FELT WASHER RETAINER
BRAKE LINING
RA PD 184149

Figure 610. Tapered roller bearing type hub.

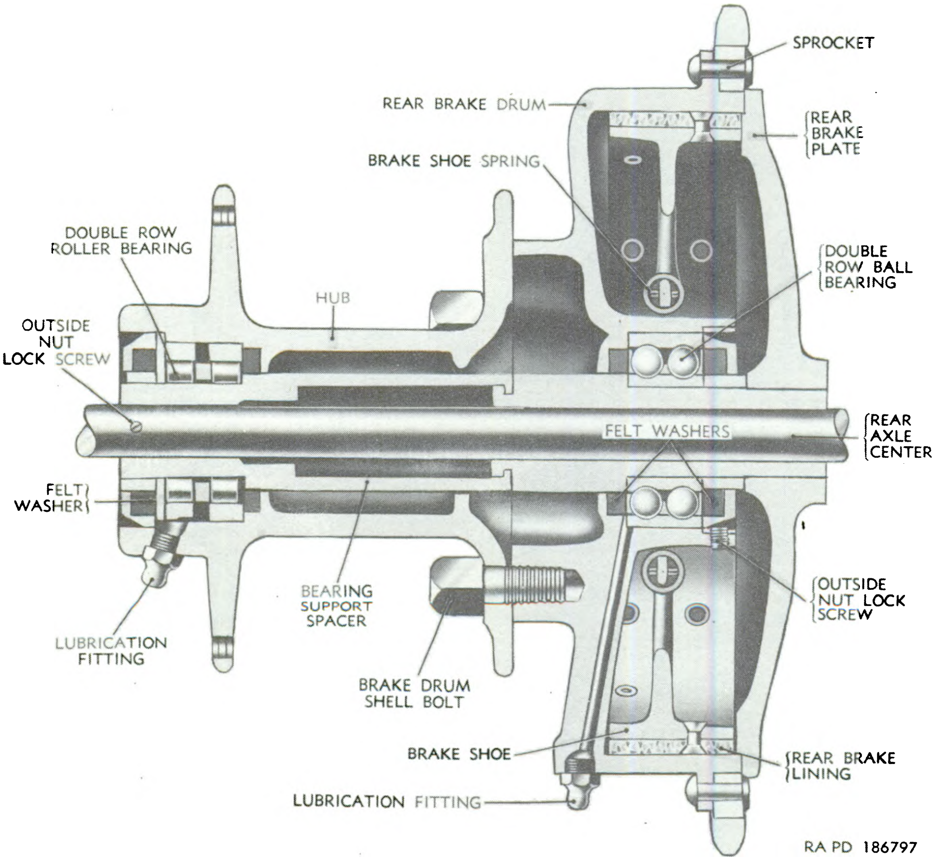

SPROCKET
REAR BRAKE DRUM
REAR BRAKE PLATE
BRAKE SHOE SPRING
DOUBLE ROW ROLLER BEARING
HUB
DOUBLE ROW BALL BEARING
OUTSIDE NUT LOCK SCREW
FELT WASHERS
REAR AXLE CENTER
FELT WASHER
OUTSIDE NUT LOCK SCREW
BEARING SUPPORT SPACER
LUBRICATION FITTING
BRAKE DRUM SHELL BOLT
BRAKE SHOE
REAR BRAKE LINING
LUBRICATION FITTING
RA PD 186797

Figure 611. Combination ball and roller bearing type hub.

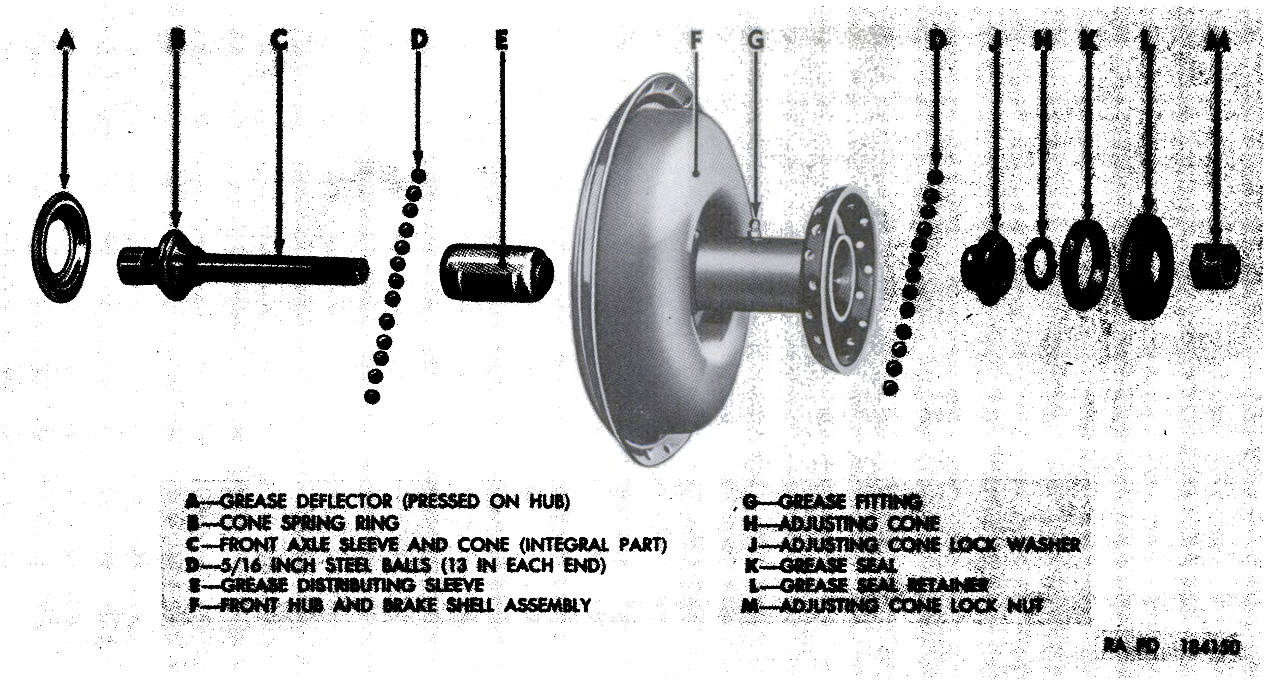

A
B
C
D
E
F
G
D
J
H
K
L
M
A—GREASE DEFLECTOR (PRESSED ON HUB)
B—CONE SPRING RING
C—FRONT AXLE SLEEVE AND CONE (INTEGRAL PART)
D—5/16 INCH STEEL BALLS (13 IN EACH END)
E—GREASE DISTRIBUTING SLEEVE
F—FRONT HUB AND BRAKE SHELL ASSEMBLY
G—GREASE FITTING
H—ADJUSTING CONE
J—ADJUSTING CONE LOCK WASHER
K—GREASE SEAL
L—GREASE SEAL RETAINER
M—ADJUSTING CONE LOCK NUT
RA PD 184150

Figure 612. Ball bearing type hub.

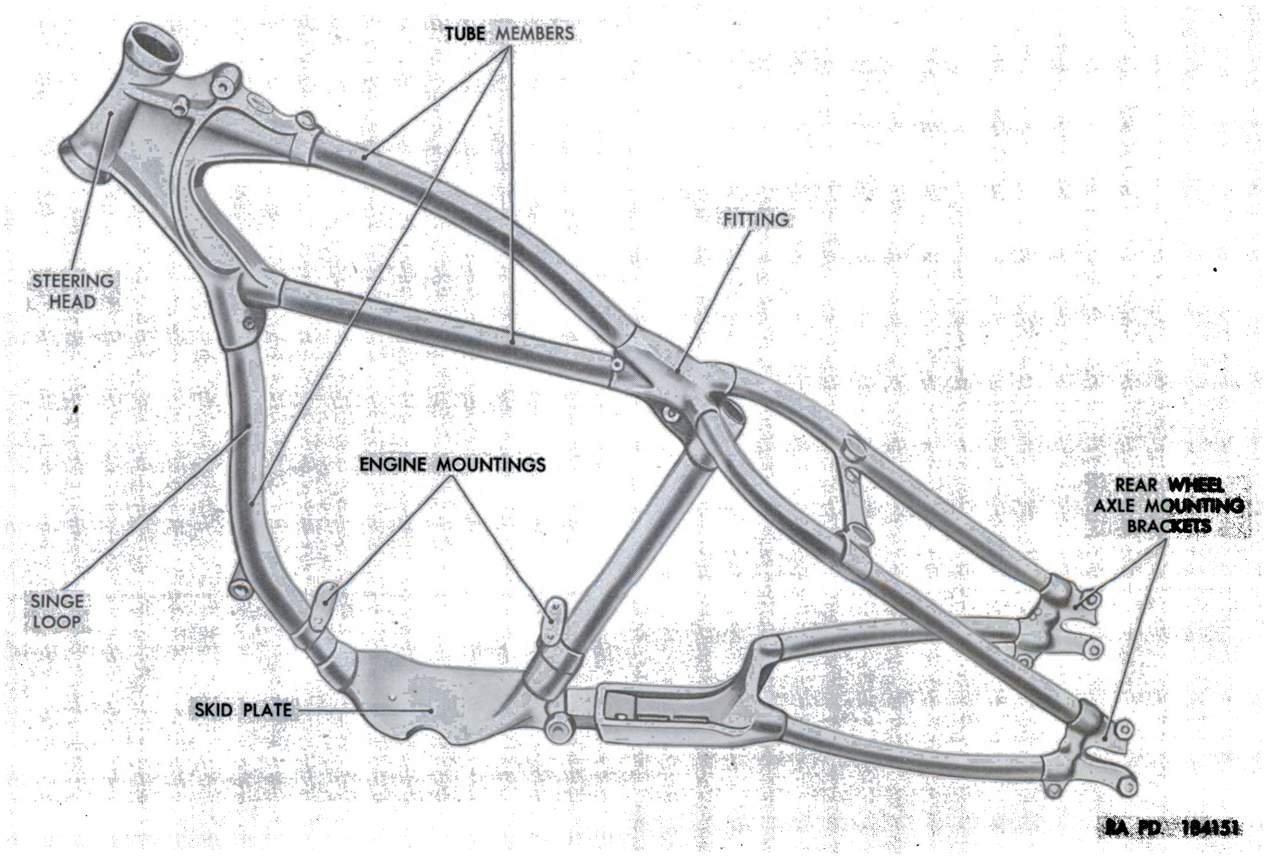

TUBE MEMBERS
FITTING
STEERING HEAD
ENGINE MOUNTINGS
REAR WHEEL AXLE MOUNTING BRACKETS
SINGE LOOP
SKID PLATE
RA PD 184151

Figure 613. Frame—single-loop type.

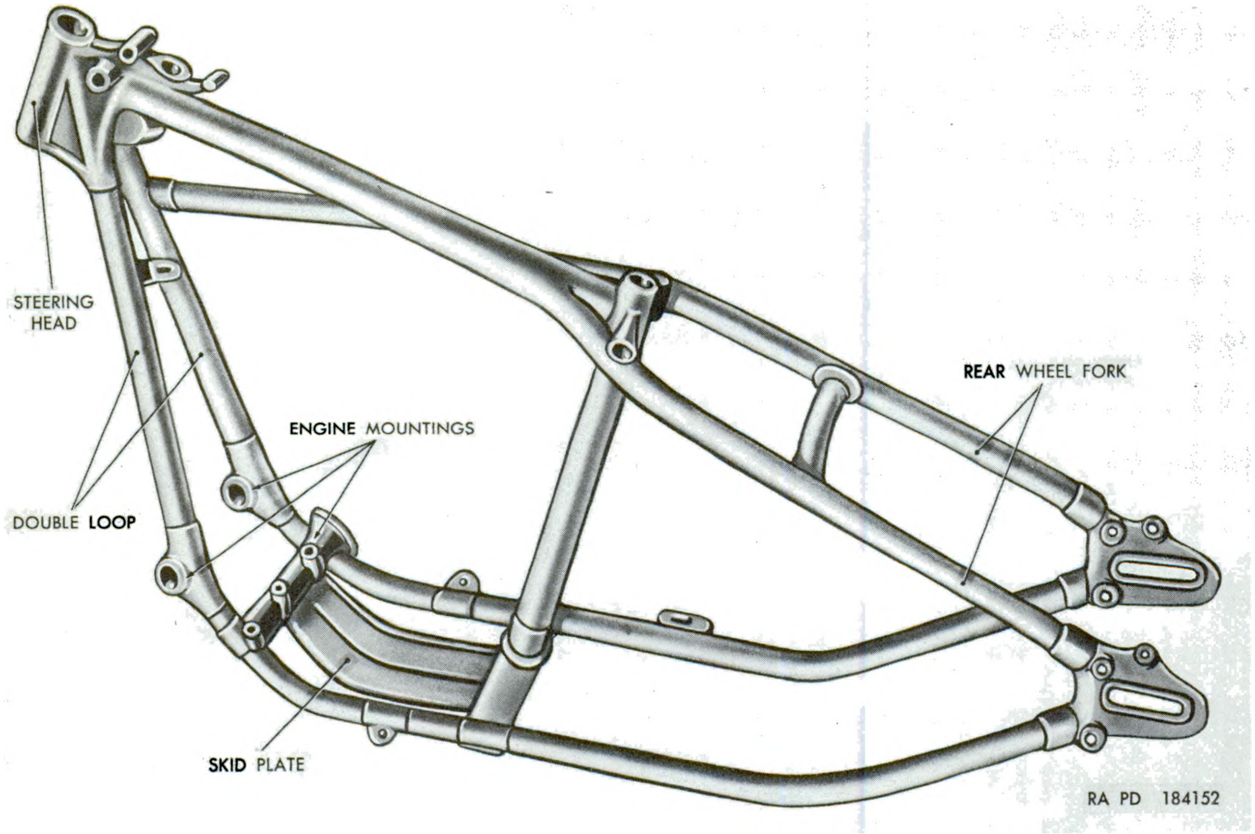

STEERING HEAD
REAR WHEEL FORK
ENGINE MOUNTINGS
DOUBLE LOOP
SKID PLATE
RA PD 184152

Figure 614. Frame—double-loop type.

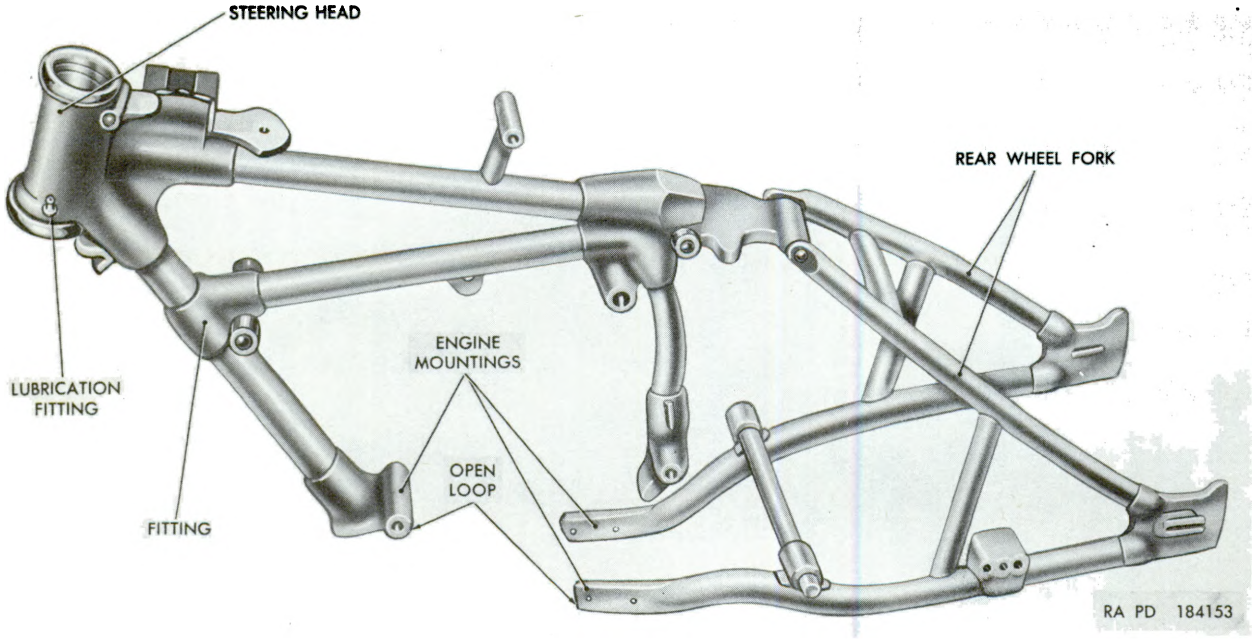

STEERING HEAD
REAR WHEEL FORK
LUBRICATION FITTING
ENGINE MOUNTINGS
OPEN LOOP
FITTING
RA PD 184153

Figure 615. Frame—open-loop, or keystone type.

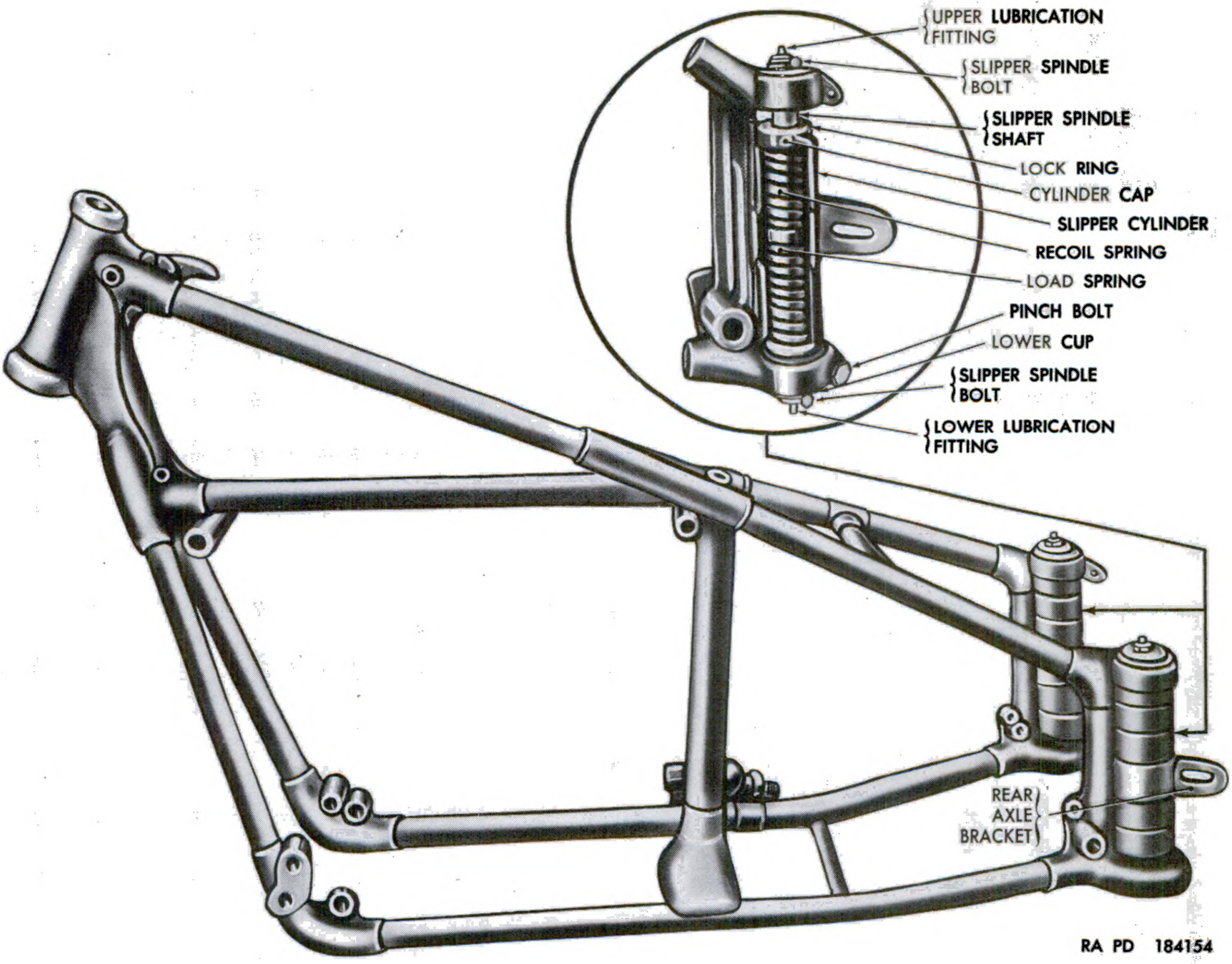

UPPER LUBRICATION FITTING
SLIPPER SPINDLE BOLT
SLIPPER SPINDLE SHAFT
LOCK RING
CYLINDER CAP
SLIPPER CYLINDER
RECOIL SPRING
LOAD SPRING
PINCH BOLT
LOWER CUP
SLIPPER SPINDLE BOLT
LOWER LUBRICATION FITTING
REAR AXLE BRACKET
RA PD 184154

Figure 616. Double-loop type frame with rear spring suspension.

347. Front Suspension and Steering

a. Front Fork. The front fork (fig. 617), assembled to the frame steering head, and the handlebars form the front suspension and steering control for the motorcycle. Cushioning springs of various types are used to absorb road shock and to prevent its transmission to the motorcycle frame. Ball bearings installed on the fork above and below steering head make steering easier.

b. Front Fork Springs. The front axle is sometimes attached to, and pivots with, the rocker arms or plates mounted at the lower end of the front fork. The rocker arms or plates pivot about connections on the rigid forks as road shock is transmitted through the front wheel and axle, allowing the spring links or spring forks to transmit the shock to the front fork springs where it is absorbed. Figure 618 illustrates a leaf-type spring mounted forward of the front axle, with the rocker arms pivoting at their centers where they are attached to the rigid forks. Figure 619 illustrates coil-type springs mounted to the rear of the front axle connections on the rocker arms. The rocker arms pivot about their rear ends, where they connect to the rigid forks. The two lower coil springs act as fork cushion springs while the two upper springs act as recoil springs. Figure 620 illustrates a type of fork to which the front axle may be directly mounted. Pivoting, to absorb road shock, takes place at the fork shackles.

c. Steering Damper.

(1) Adjustable steering dampers are friction devices to damp the turning action of the front forks and steady the front wheel at high speed or on rough terrain.

(2) Friction dampers are sometimes provided to control the action of the fork shackles and coil springs on installations

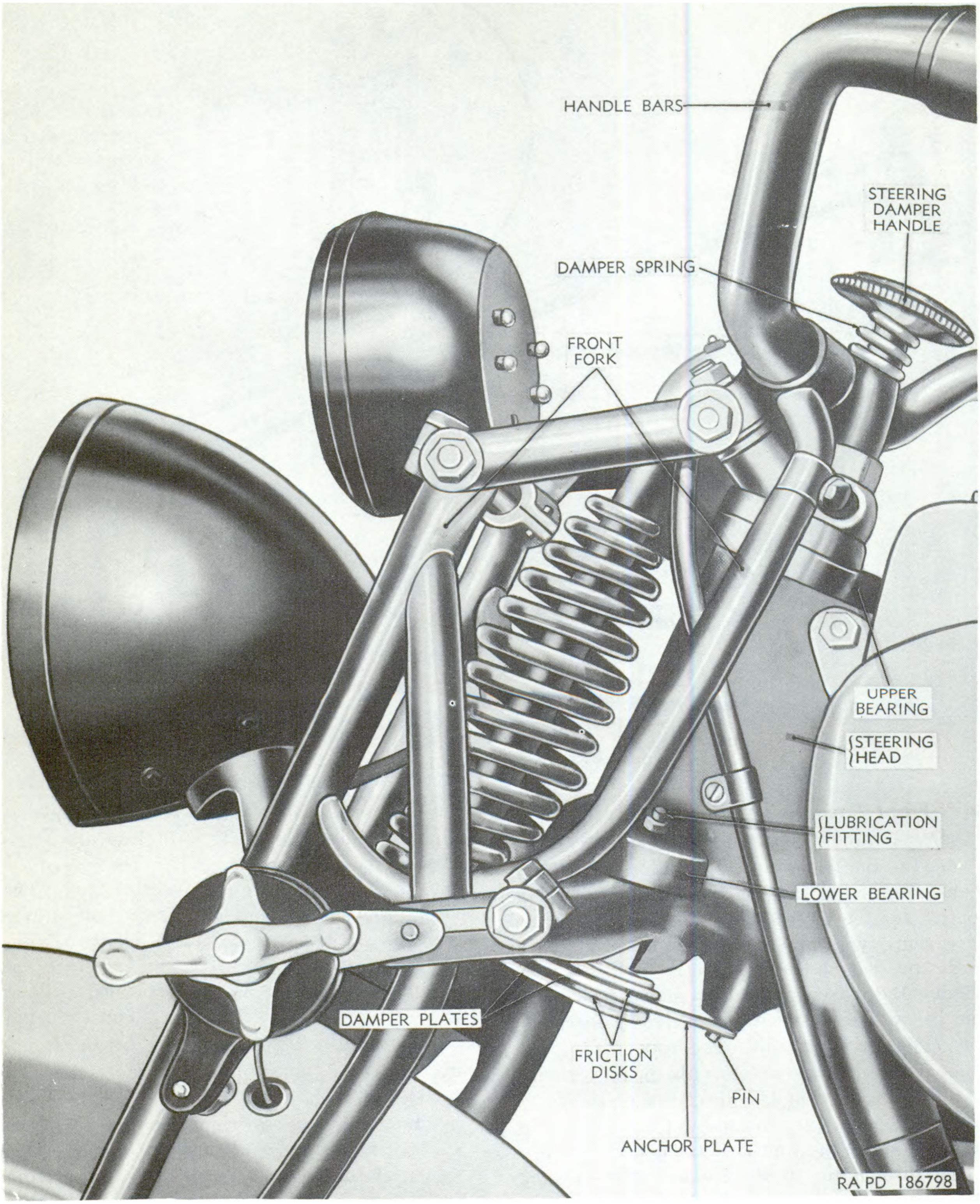

HANDLE BARS
STEERING DAMPER HANDLE
DAMPER SPRING
FRONT FORK
UPPER BEARING
STEERING HEAD
LUBRICATION FITTING
LOWER BEARING
DAMPER PLATES
FRICTION DISKS
PIN
ANCHOR PLATE
RA PD 186798

Figure 617. Front suspension and steering control.

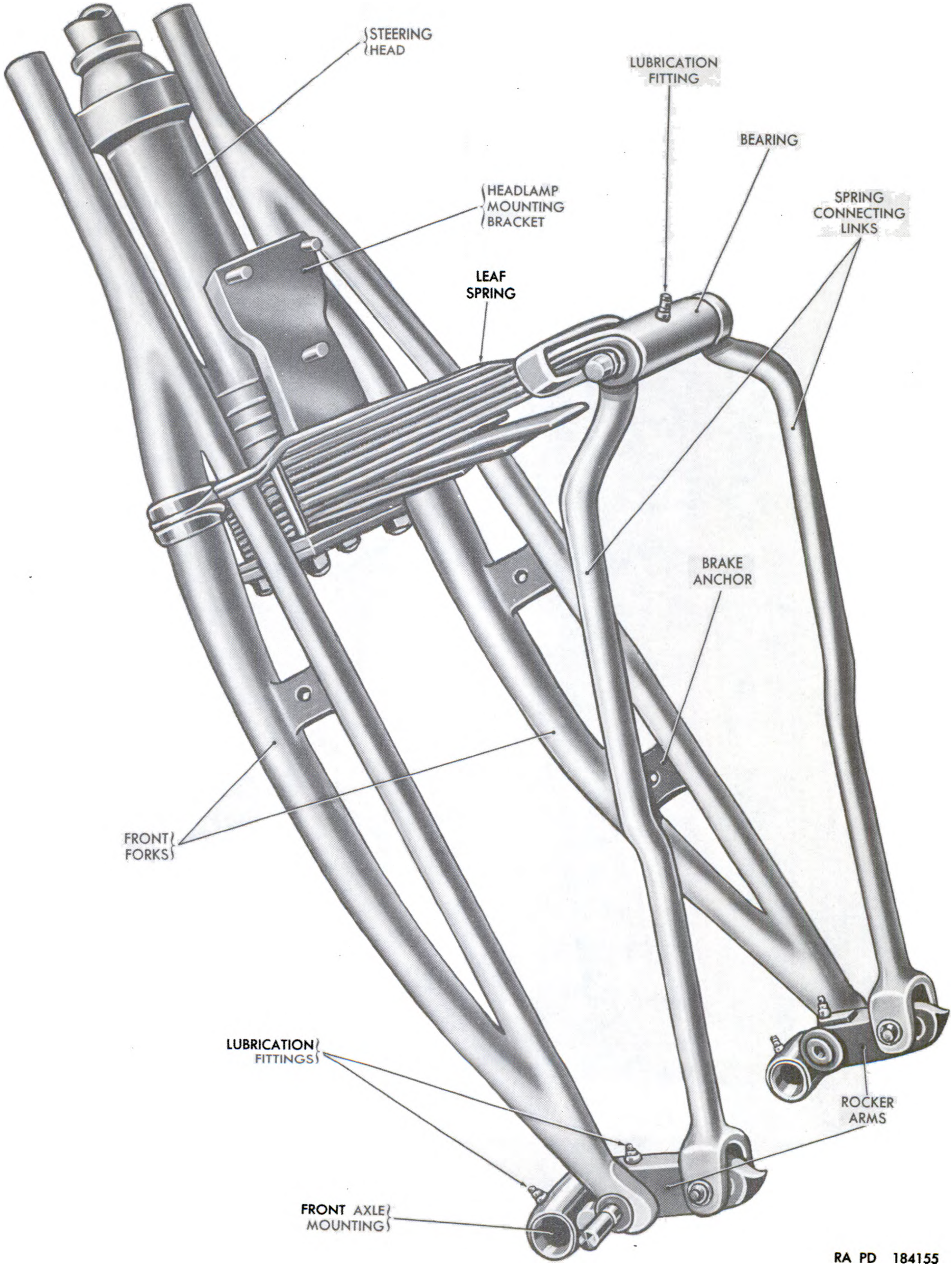

STEERING HEAD
LUBRICATION FITTING
BEARING
HEADLAMP MOUNTING BRACKET
SPRING CONNECTING LINKS
LEAF SPRING
BRAKE ANCHOR
FRONT FORKS
LUBRICATION FITTINGS
ROCKER ARMS
FRONT AXLE MOUNTING
RA PD 184155

Figure 618. Leaf spring front suspension.

such as that shown in figure 620. They act much like the shock absorbers used on trucks and other vehicles. That is, they dampen out spring oscillations and prevent excessive wheel bounce.

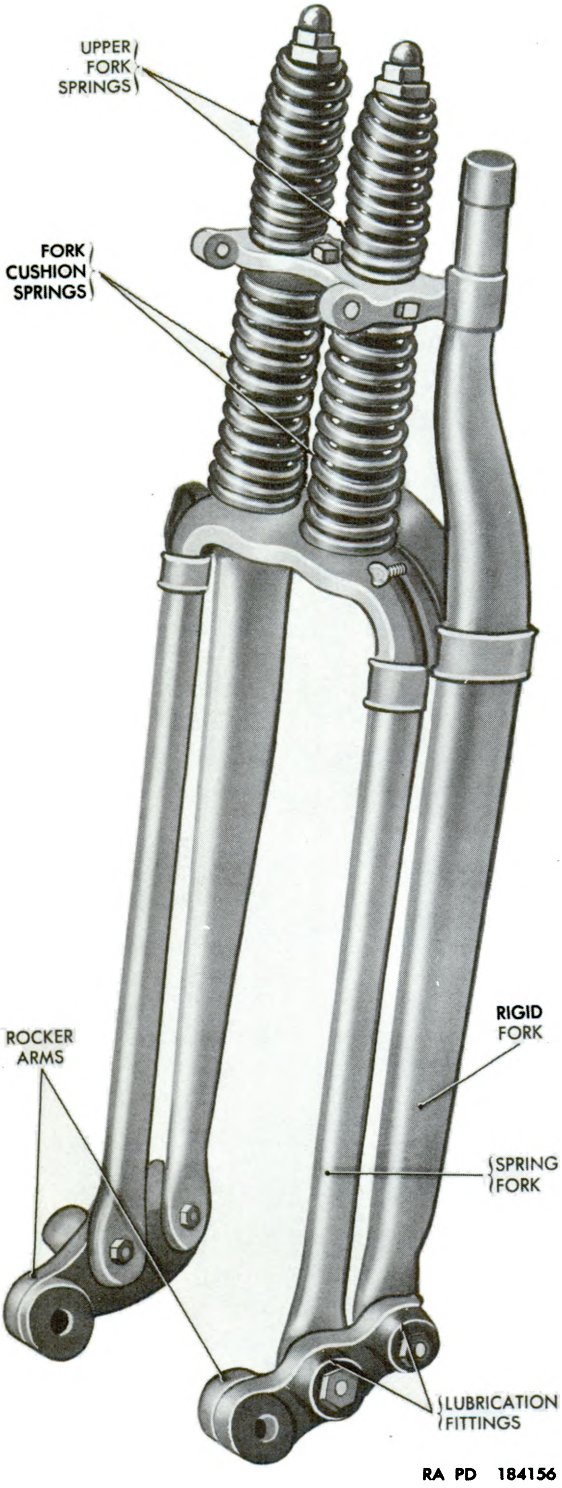

UPPER FORK SPRINGS
FORK CUSHION SPRINGS
ROCKER ARMS
RIGID FORK
SPRING FORK
LUBRICATION FITTINGS
RA PD 184156

Figure 619. Coil spring front suspension.

348. Saddles and Seat Posts

The motorcycle saddle, which resembles a cavalry saddle, is attached at its front end, or pommel, to the frame. It is cushioned on two coil springs or attached at the center of its support to a seat post (fig. 621). The lower end at the seat post rests on a coil spring and slides inside the seat-post tube. The rear end, or cantle, of the seat-post saddle can be raised to make the battery or oil tank more accessible by removing the

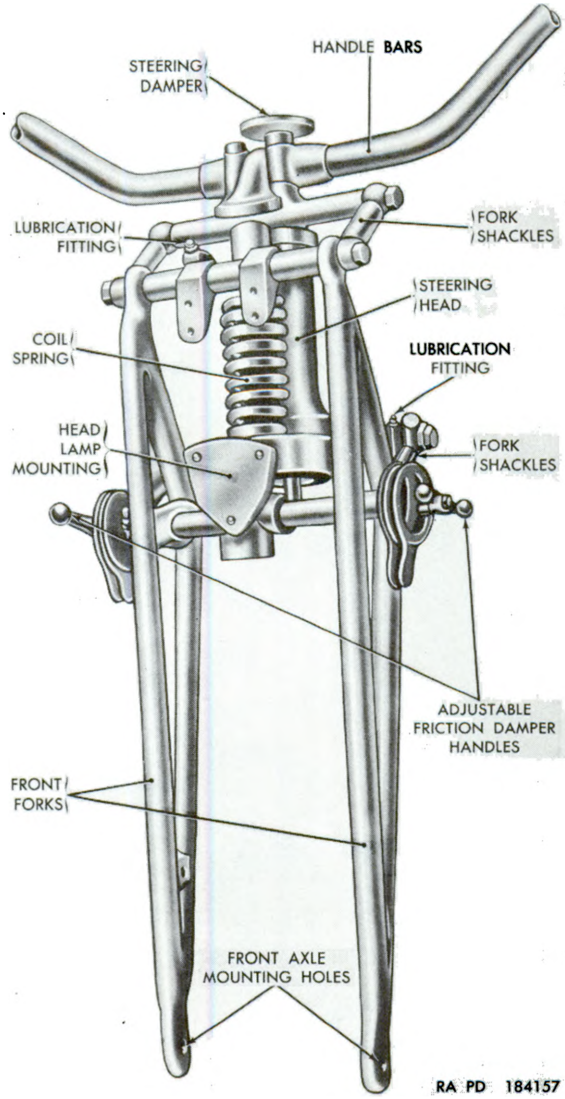

STEERING DAMPER
HANDLE BARS
LUBRICATION FITTING
FORK SHACKLES
STEERING HEAD
COIL SPRING
LUBRICATION FITTING
HEAD LAMP MOUNTING
FORK SHACKLES
ADJUSTABLE FRICTION DAMPER HANDLES
FRONT FORKS
FRONT AXLE MOUNTING HOLES
RA PD 184157

Figure 620. Front suspension with upper fork shackles.

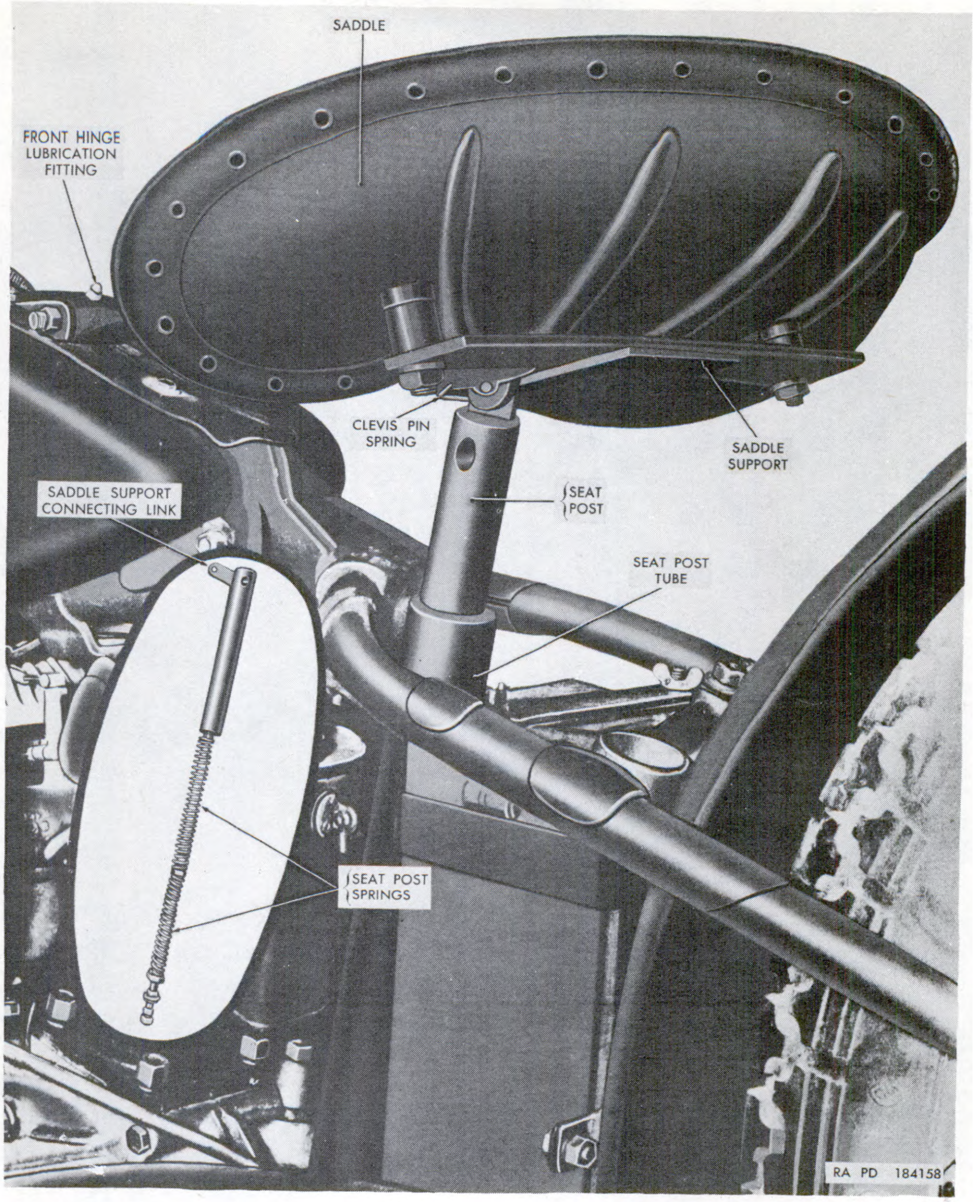

SADDLE
FRONT HINGE LUBRICATION FITTING
CLEVIS PIN SPRING
SADDLE SUPPORT
SADDLE SUPPORT CONNECTING LINK
SEAT POST
SEAT POST TUBE
SEAT POST SPRINGS
RA PD 184158

Figure 621. Saddle and seat post.

clevis pin which connects the saddle support to the seat post.

349. Brakes

a. Mechanical, internal-expanding brakes (par. 285) are used on motorcycles. The front wheel brake is hand-operated by means of a lever on the handlebar; the rear wheel brake is operated through a brake foot pedal, accessible to the driver's right foot.

b. The brakeshoes are held against the operating cam by return springs (fig. 622). When the brake mechanism is actuated, the cam rotates, causing the brakeshoes to separate as they pivot about the stud at their lower ends, thereby applying the brake.

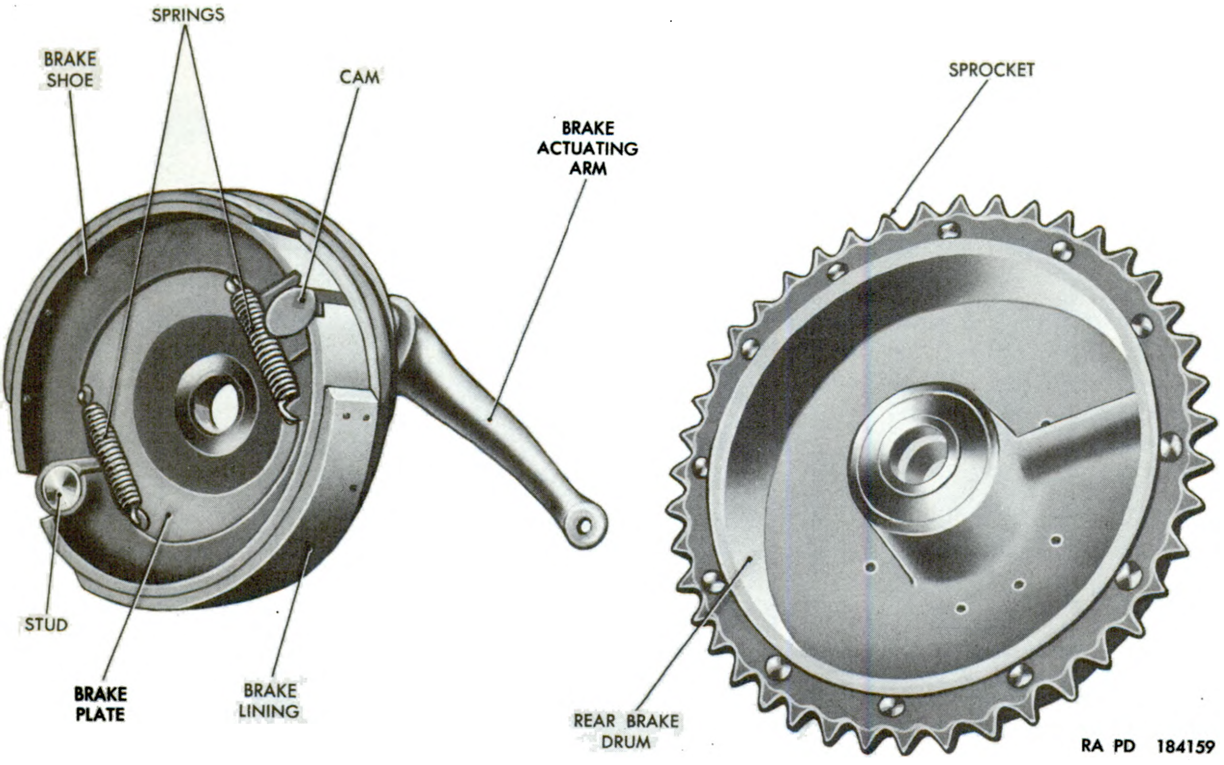


Figure 622. Motorcycle brake.

Section III. ENGINE

350. General

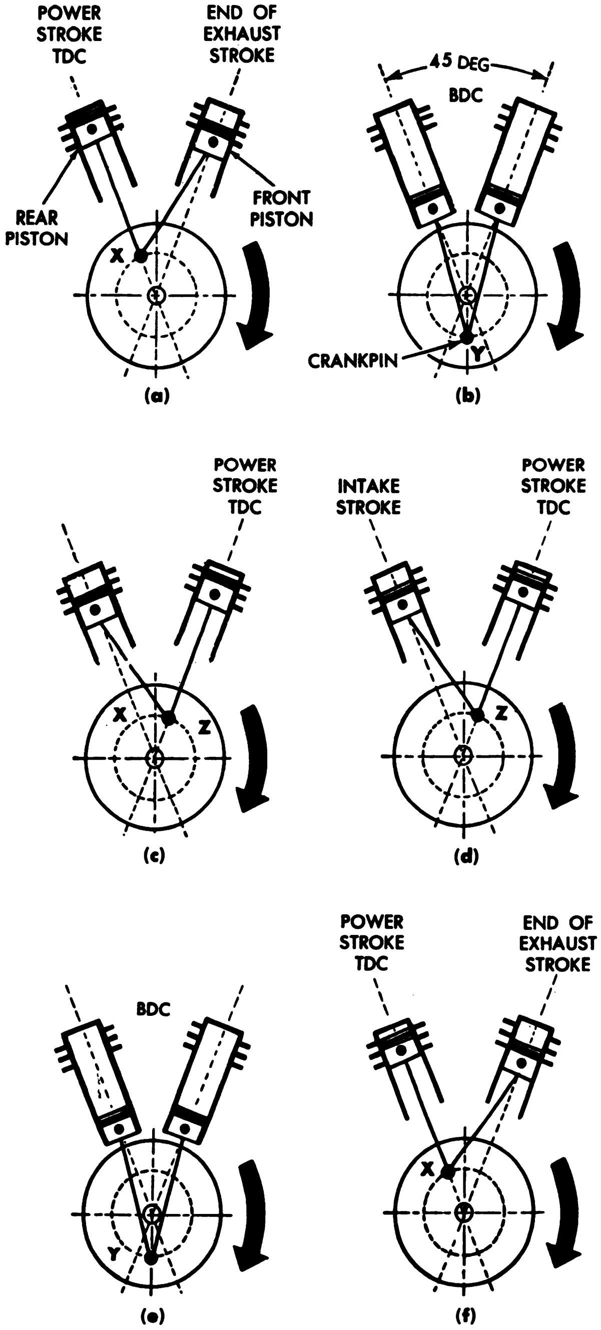
Motorcycles are powered by air-cooled, 2-cylinder, 4-stroke cycle gasoline engines (par. 9). The L-head cylinders are arranged in a **V**-shape of 42° or 45° (par. 21).

351. Firing Order and Power Delivery

a. The two cylinders are placed on the crankcase at an angle with each other to form the "V" (fig. 624). The two connecting rods are attached to a single crankpin, causing the pistons to reciprocate almost in unison, slightly out of phase. Valve timing is arranged so that while one of the pistons is on its power stroke, the second is on its intake stroke. The slightly out-of-phase reciprocation of the two pistons in the 2-cylinder, V-type engine makes it possible to obtain even firing and smooth operation.

b. Assuming the rear piston is at its top dead center position, just commencing its power stroke, as shown in (*a*), figure 623, the front piston will be just ending its exhaust stroke. The common crankpin for the two connecting rods is at point X. When the crankpin reaches point Y at the bottom of its travel (*b*), fig. 623, the two pistons are at bottom dead center. For the front piston to go from bottom dead center through its compression stroke to top dead center, the crankpin must travel from position Y, 45° past position X, to position Z ((*c*), fig. 623). The crankpin and flywheel must, therefore, travel a total of 360° plus 45°, or 405° from the beginning of the rear piston power stroke to the beginning of the front piston power stroke.

c. With the front piston starting its power stroke ((*d*), fig. 623), the rear piston is at the beginning of its intake stroke. When both pistons are at bottom dead center ((*e*), fig. 623) the front piston is ready for its exhaust stroke and the rear piston its compression stroke. To put the rear piston in position for its power stroke, the crankpin must rotate from point Y bottom dead center to point X ((*f*), fig. 623). The flywheel rotates only 315° from point Z to point X, between the beginning of the front piston power stroke to the beginning of the rear piston power stroke, or 45° less than a full 360° revolution.



RA PD 184160

Figure 623. Operation of 2-cylinder, 4-stroke cycle, V-type engine.

352. Crankcase Cylinders and Pistons

The crankcase, cylinders and cylinder heads are individual units, and are bolted together to form the engine (fig. 624). The cylinders and cylinder heads are deeply finned for rapid dissipation of heat. Pistons are camground (par. 23) and have horizontal or T-slots for expansion as they heat up during operation. Piston pins are generally of the full-floating type (par. 25). A typical engine cylinder and cylinder head are shown in a cross sectional view in figure 625.

353. Connecting Rods, Crankshaft, and Flywheels

The connecting rods in 2-cylinder, V-type engines (fig. 626) are of the fork (male and female) type, assembled to one crankpin on a roller bearing. The crankshaft consists of two main shafts carrying two flywheels (fig. 627) which are separated by the eccentrically attached connecting rod crankpin. The flywheels are the arms of a single-throw crankshaft. Counterweights are cast integrally on the flywheels opposite the crankpin bosses to balance the crankpin weight. One of the main shafts carriers the primary drive sprocket while the other carries the timing-mechanism-drive pinion gear. For proper operation, the flywheels must be exactly parallel, true, and balanced.

354. Valves and Valve Timing

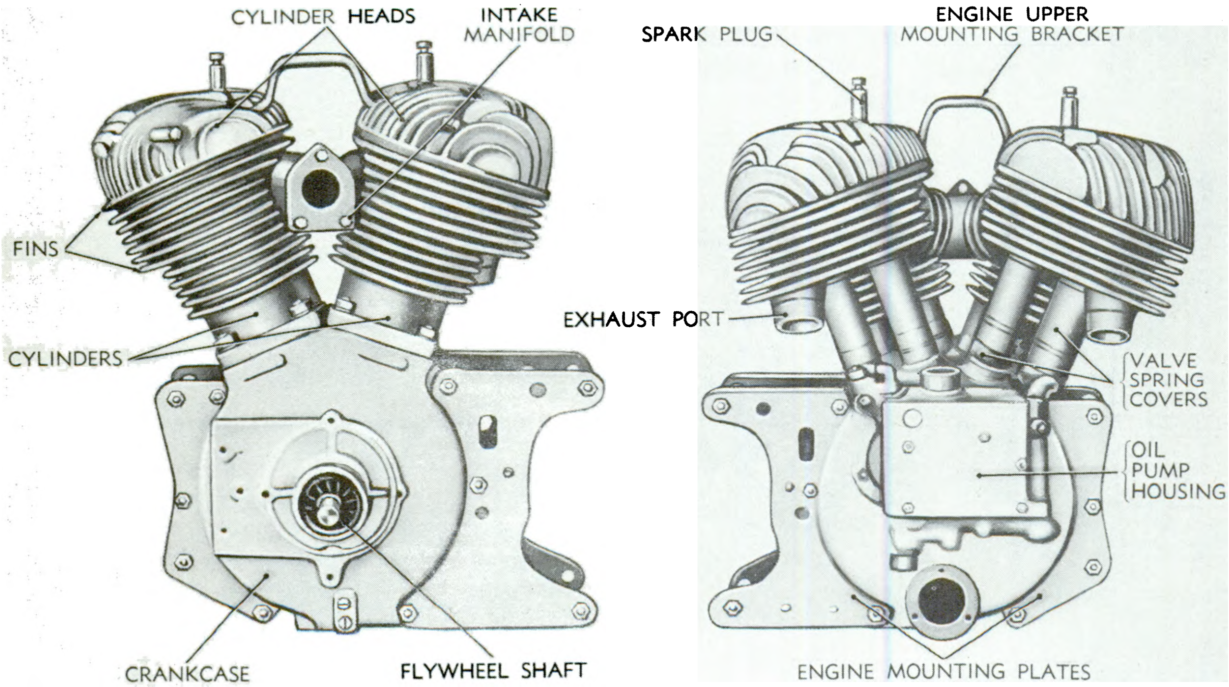
a. Valves and timing mechanisms in motorcycle engines are similar in principle to those used in other automotive vehicles (par. 11). Because of the high speeds of motorcycle engines, valve cams are designed to lift the valves and close them as rapidly as possible.

b. One type of valve mechanism employs two cam gears (fig. 628), one for each cylinder. Each cam gear drives the intake and exhaust valve lift levers for its cylinders.

c. Another valve mechanism uses a cam gear (fig. 629) for each valve, lifting the valves through roller-type tappets.

355. Lubrication

a. General. Motorcycle engine bearings, piston rings, cylinder walls, bushings, and gears are lubricated by a combination force feed and splash, dry sump system which is controlled by a feed pump and a scavenger pump. The oil feed pump circulates oil to the various engine parts, while the oil scavenger pump returns the oil to the oil tank. The crankcase does not contain a constant level of oil at any time. The oil is contained in an oil tank which is a separate unit or, as in some models, is a built-in compartment of the reserve fuel tank with a separate filler neck and cap. The oil is cooled as it circulates through the exterior lines to the oil tank.


CYLINDER HEADS
INTAKE MANIFOLD
FINS
CYLINDERS
CRANKCASE
FLYWHEEL SHAFT
SPARK PLUG
ENGINE UPPER MOUNTING BRACKET
EXHAUST PORT
VALVE SPRING COVERS
OIL PUMP HOUSING
ENGINE MOUNTING PLATES

LEFT SIDE **RIGHT SIDE**

RA PD 186800

Figure 624. Two-cylinder, 4-stroke cycle, V-type engine assembly.

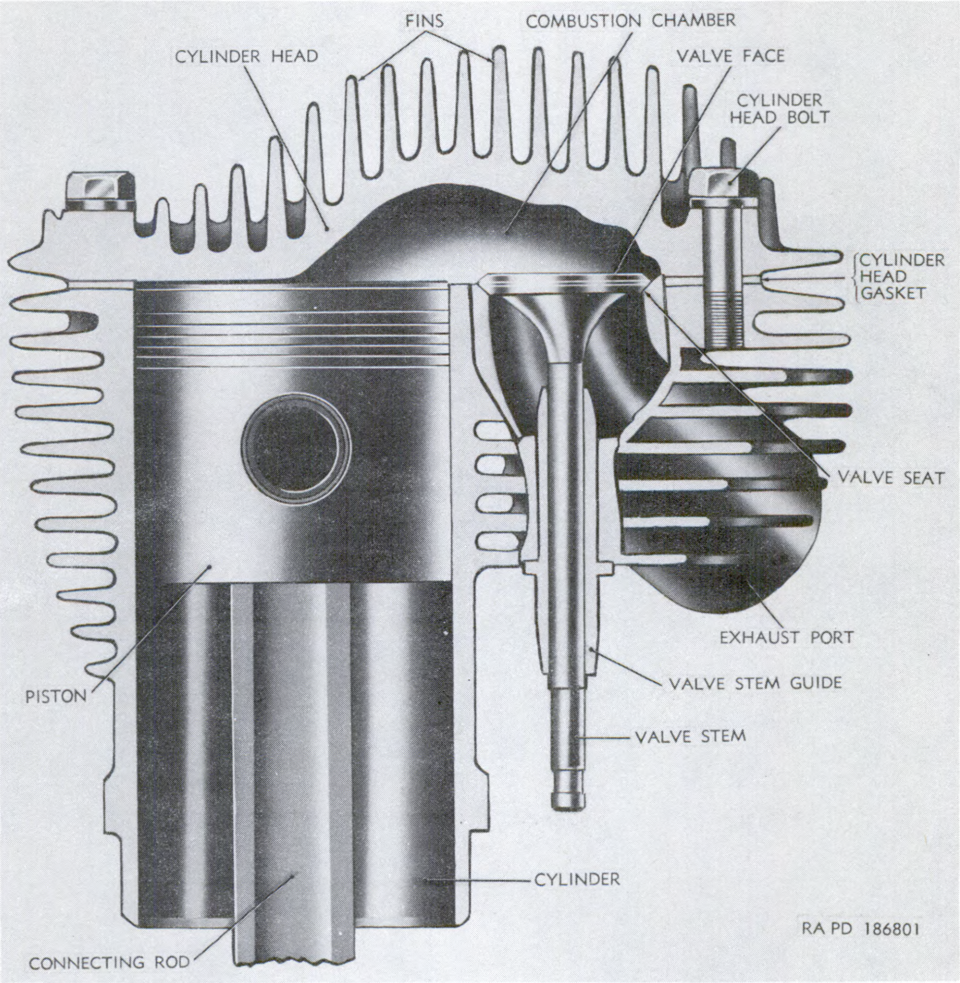

FINS
COMBUSTION CHAMBER
CYLINDER HEAD
VALVE FACE
CYLINDER HEAD BOLT
CYLINDER HEAD GASKET
VALVE SEAT
EXHAUST PORT
VALVE STEM GUIDE
PISTON
VALVE STEM
CYLINDER
RA PD 186801
CONNECTING ROD

Figure 625. Engine cylinder and cylinder head—cross sectional view.

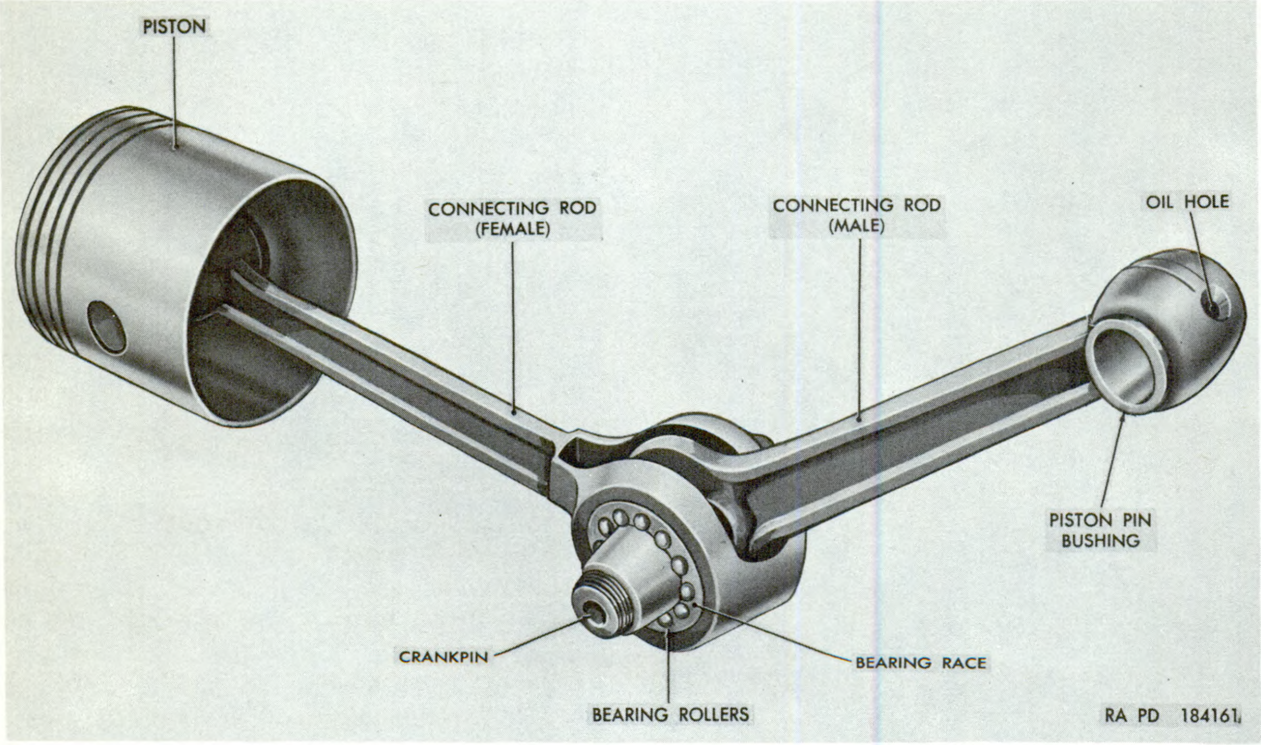

PISTON
CONNECTING ROD (FEMALE)
CONNECTING ROD (MALE)
OIL HOLE
PISTON PIN BUSHING
CRANKPIN
BEARING RACE
BEARING ROLLERS
RA PD 184161

Figure 626. Two-cylinder, V-type engine connecting rods.

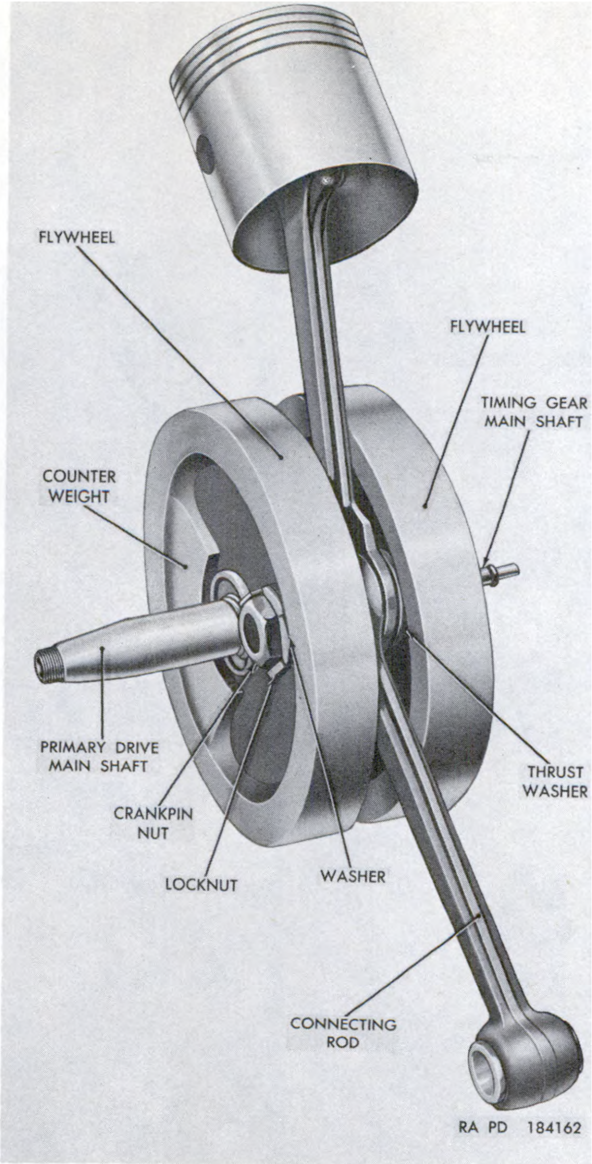


Figure 627. Two-cylinder, V-type engine crank-shaft and flywheels.

b. Combination Feed and Scavenger Oil Pump.

(1) The feed pump and scavenger pump can be combined in one housing or installed as separate units. In a combination unit (fig. 630), the feed pump is a rotating, reciprocating, plunger type. A worm gear, driven by a gear on the camshaft drive of the engine timing gear train, forms the lower part of the plunger. The worm gear and drive cause the plunger to rotate. An inclined slot, cut around the center portion of the plunger, rides on a pin that is fixed to the pump housing. The inclination of the slot, bearing against the fixed pin, causes the plunger to move up and down, or reciprocate, as it is rotated by the worm gear. The upper part of the plunger consists of a well, at the bottom of which is a cross or hole channel. On the downward, or suction, stroke of the plunger, the cross hole is opened to the inlet passage in the pump housing that connects to the oil inlet pipe from the oil tank. The oil flows by gravity through the cross channel into the plunger well and into the clearance space above the plunger. As the plunger rotates, it starts upward on its compression stroke. The cross hole is rotated around and connects to the oil outlet opening leading to the various engine parts. The oil contained in the plunger well and in the clearance space is forced through the outlet opening to the crankshaft main bearing and connecting rod lower bearing. From here the oil is splashed to the other bearings and to the pistons and cylinders. The oil then drains to the sump at the bottom of the crankcase. The scavenger pump draws the oil from the sump and returns it to the oil tank.

(2) The scavenger pump portion of the combination unit is driven by the distributor shaft. A crankcase sump valve, connected to the inlet of the scavenger pump, prevents oil from flowing back into the crankcase when the engine is stopped. The suction created by the scavenger pump in operation lifts a valve disk against the pressure of a coil spring, allowing oil from the sump to be drawn into the sump valve housing, where it is filtered by a wire screen. When the scavenger pump stops, the disk is forced onto its seat by the spring, stopping the flow of oil from the sump valve to the crankcase. The scavenger pump is of the gear type which draws oil from the sump and forces it under pressure through the return passage to the oil tank. The scavenger pump has a larger capacity than the feed pump to prevent oil accumulation in the crankcase.

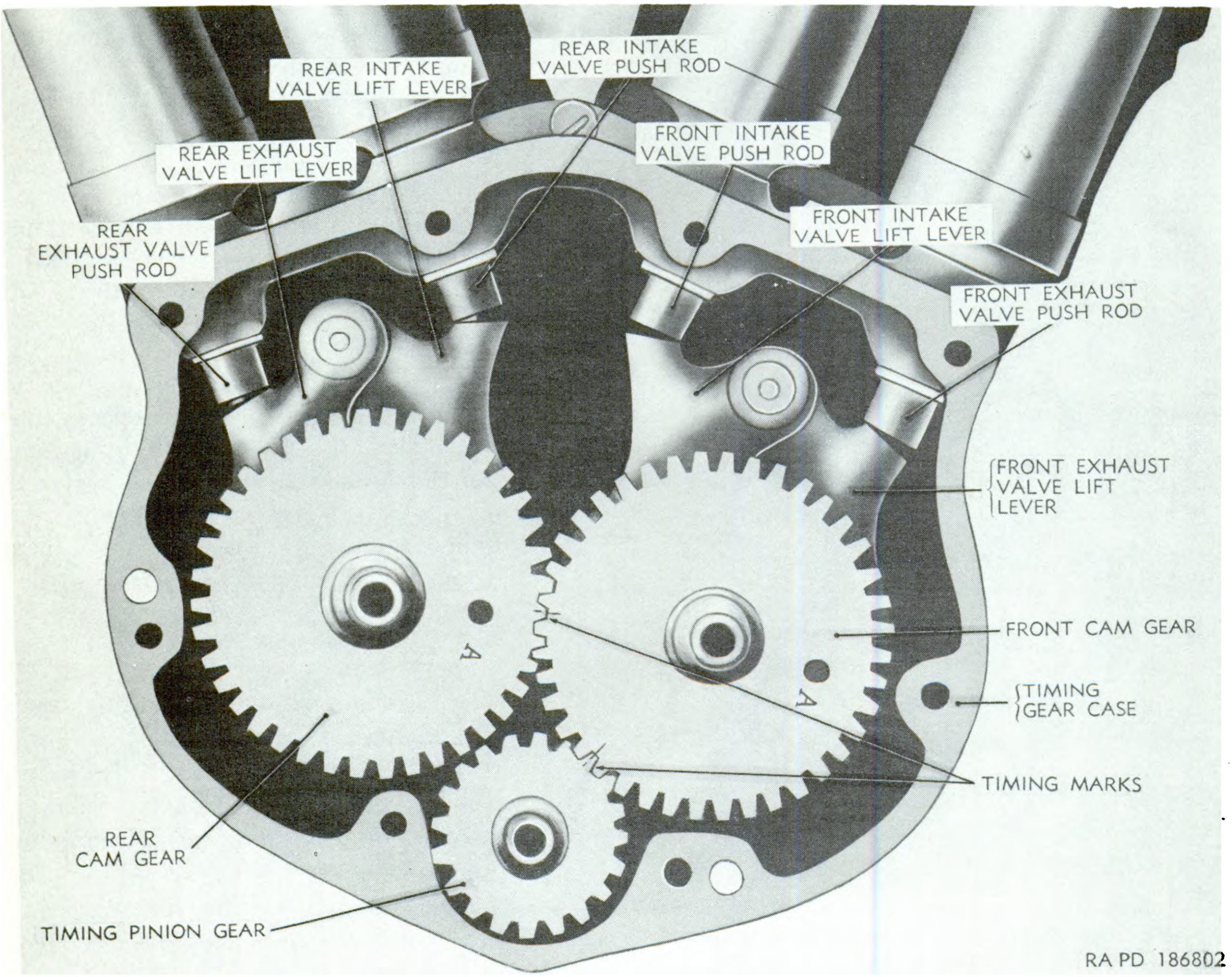

REAR INTAKE VALVE PUSH ROD
REAR INTAKE VALVE LIFT LEVER
REAR EXHAUST VALVE LIFT LEVER
FRONT INTAKE VALVE PUSH ROD
REAR EXHAUST VALVE PUSH ROD
FRONT INTAKE VALVE LIFT LEVER
FRONT EXHAUST VALVE PUSH ROD
FRONT EXHAUST VALVE LIFT LEVER
FRONT CAM GEAR
TIMING GEAR CASE
TIMING MARKS
REAR CAM GEAR
TIMING PINION GEAR
A
A
RA PD 186802

Figure 628. Timing gear train with dual-lift valve mechanism.

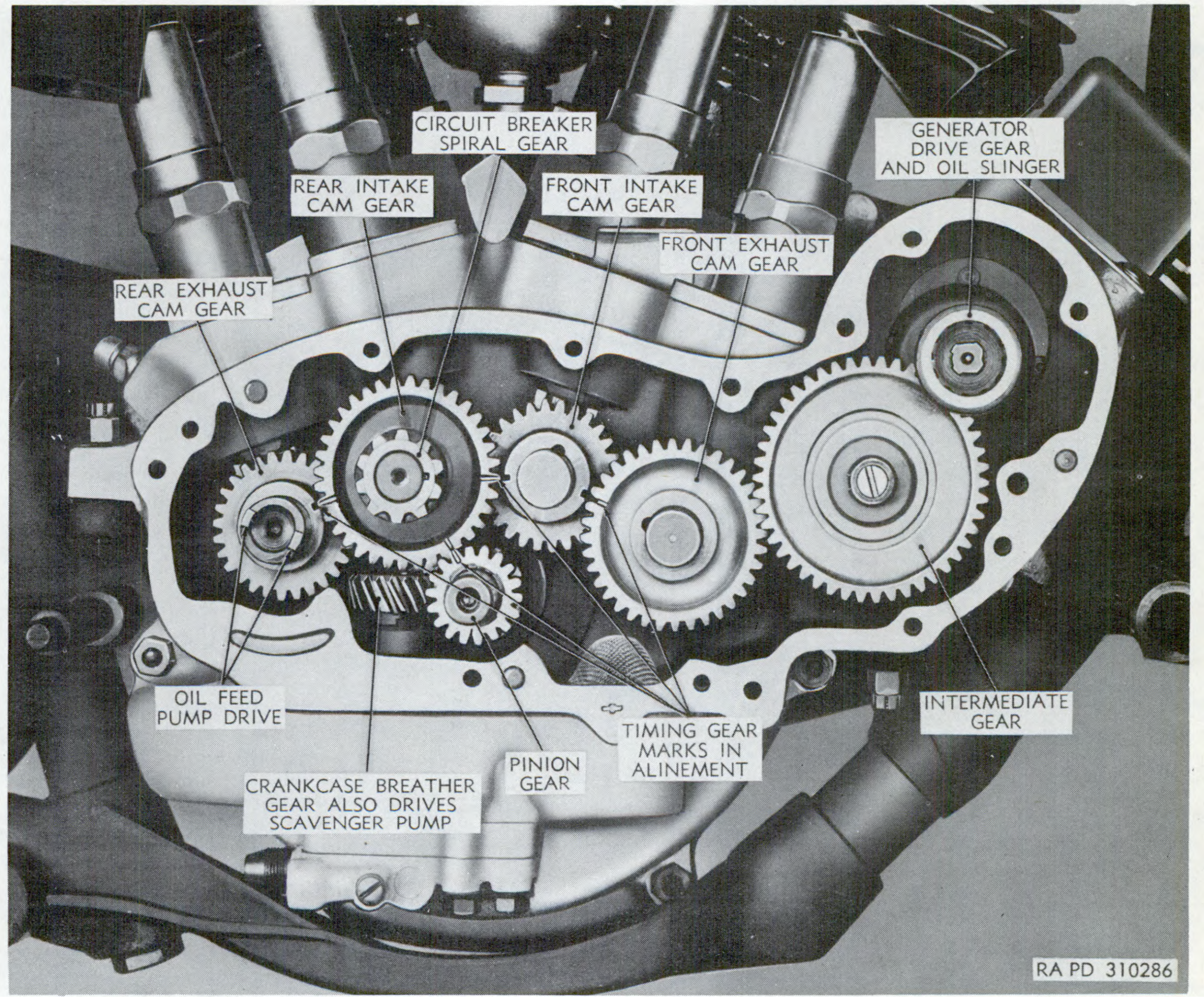
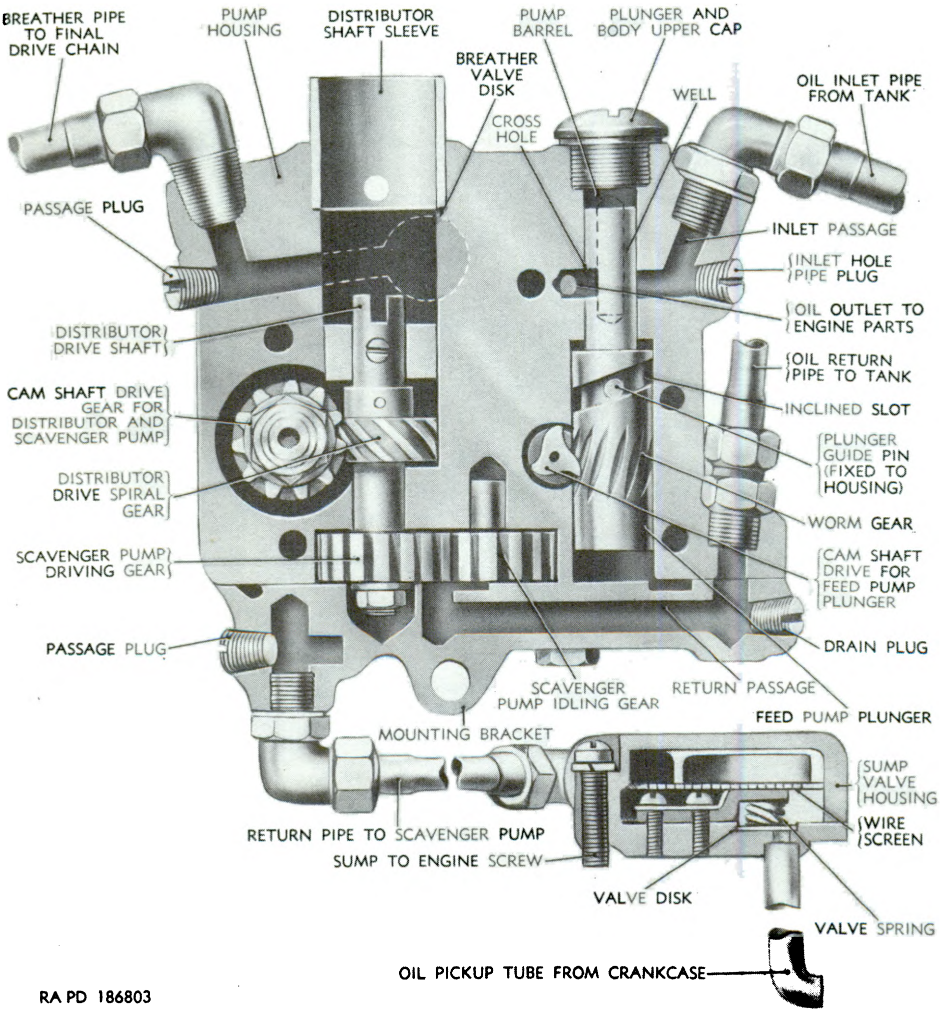
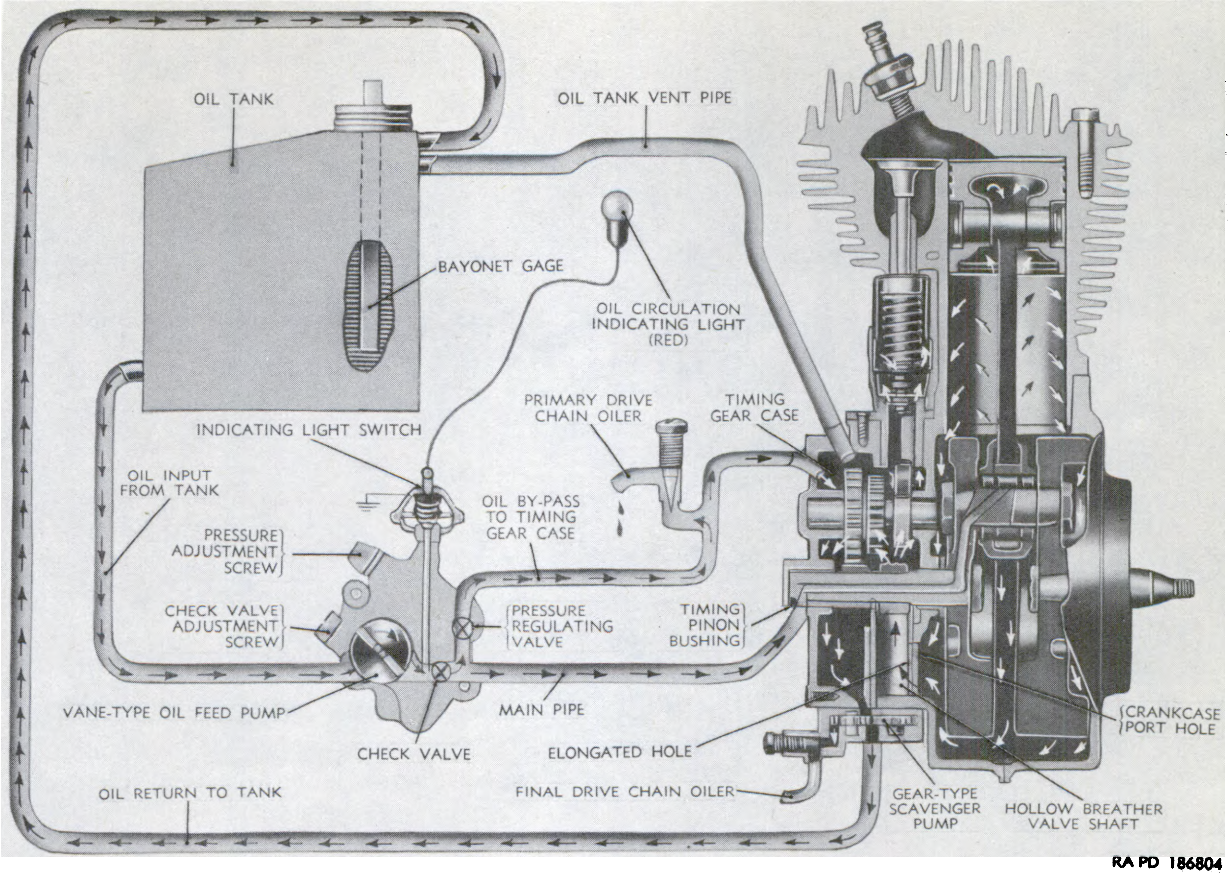

CIRCUIT BREAKER SPIRAL GEAR
GENERATOR DRIVE GEAR AND OIL SLINGER
REAR INTAKE CAM GEAR
FRONT INTAKE CAM GEAR
FRONT EXHAUST CAM GEAR
REAR EXHAUST CAM GEAR
OIL FEED PUMP DRIVE
TIMING GEAR MARKS IN ALINEMENT
INTERMEDIATE GEAR
PINION GEAR
CRANKCASE BREATHER GEAR ALSO DRIVES SCAVENGER PUMP
RA PD 310286

***Figure 629.* Timing gear train with individual cam gears.**


BREATHER PIPE TO FINAL DRIVE CHAIN
PUMP HOUSING
DISTRIBUTOR SHAFT SLEEVE
BREATHER VALVE DISK
PUMP BARREL
PLUNGER AND BODY UPPER CAP
CROSS HOLE
WELL
OIL INLET PIPE FROM TANK
PASSAGE PLUG
INLET PASSAGE
INLET HOLE PIPE PLUG
OIL OUTLET TO ENGINE PARTS
DISTRIBUTOR DRIVE SHAFT
OIL RETURN PIPE TO TANK
INCLINED SLOT
CAM SHAFT DRIVE GEAR FOR DISTRIBUTOR AND SCAVENGER PUMP
PLUNGER GUIDE PIN (FIXED TO HOUSING)
DISTRIBUTOR DRIVE SPIRAL GEAR
WORM GEAR
SCAVENGER PUMP DRIVING GEAR
CAM SHAFT DRIVE FOR FEED PUMP PLUNGER
PASSAGE PLUG
DRAIN PLUG
SCAVENGER PUMP IDLING GEAR
RETURN PASSAGE
FEED PUMP PLUNGER
MOUNTING BRACKET
SUMP VALVE HOUSING
WIRE SCREEN
RETURN PIPE TO SCAVENGER PUMP
SUMP TO ENGINE SCREW
VALVE DISK
VALVE SPRING
OIL PICKUP TUBE FROM CRANKCASE

RA PD 186803

Figure 630. Combination feed and scavenger oil pump.


OIL TANK
OIL TANK VENT PIPE
BAYONET GAGE
OIL CIRCULATION INDICATING LIGHT (RED)
PRIMARY DRIVE CHAIN OILER
TIMING GEAR CASE
INDICATING LIGHT SWITCH
OIL INPUT FROM TANK
OIL BY-PASS TO TIMING GEAR CASE
PRESSURE ADJUSTMENT SCREW
CHECK VALVE ADJUSTMENT SCREW
PRESSURE REGULATING VALVE
TIMING PINON BUSHING
VANE-TYPE OIL FEED PUMP
MAIN PIPE
CRANKCASE PORT HOLE
CHECK VALVE
ELONGATED HOLE
OIL RETURN TO TANK
FINAL DRIVE CHAIN OILER
GEAR-TYPE SCAVENGER PUMP
HOLLOW BREATHER VALVE SHAFT

RA PD 186804

Figure 631. Separate feed and scavenger oil pump lubrication system.

c. Separate Feed and Scavenger Oil Pump System.

(1) A lubrication system incorporating separate feed and scavenger pumps is illustrated in figure 631. The feed pump (fig. 632) is a vane type unit (par. 101). The rotor, driven by the rear exhaust cam gear (fig. 629), causes two sliding vanes, or blades, to revolve within the slightly eccentric chamber. Oil is forced by the feed pump through the main pipe to the timing pinion bushing-type bearing. An elongated cross hole, located in the flywheel timing gear shaft, registers with the pinion bearing hole as it passes on every upward stroke of the pistons. The oil then flows through the various passageways of the flywheel shaft, flywheel, and crankpin to the lower connecting rod bearings. As the piston moves upward, it draws with it drops of oil forced out of the connecting rod bearings, which lubricate the cylinder walls and piston pins.

(2) A centrifugal valve has been built into the rotor of vane type feed pumps (figs. 632 and 633). At low and intermediate speeds, the valve remains open, allowing oil to be pumped to crankpin and bypassing the pressure regulating valve leading to the timing gears (fig. 631). The oil pressure is therefore low, at low and intermediate speeds. As the engine speed increases, the centrifugal valve closes tighter, gradually increasing the oil pressure to the limit for which the pressure regulating valve is set. The oil pressure at the crankpin is determined by the engine speed up to the maximum, which is the setting of the pressure regulating valve. More oil is fed to the engine at high speeds due to the higher pressure, while less oil is fed at low engine speeds, preventing oil accumulation in the crankcase.

(3) When the piston begins to move down, the timing pinion bearing hole is closed

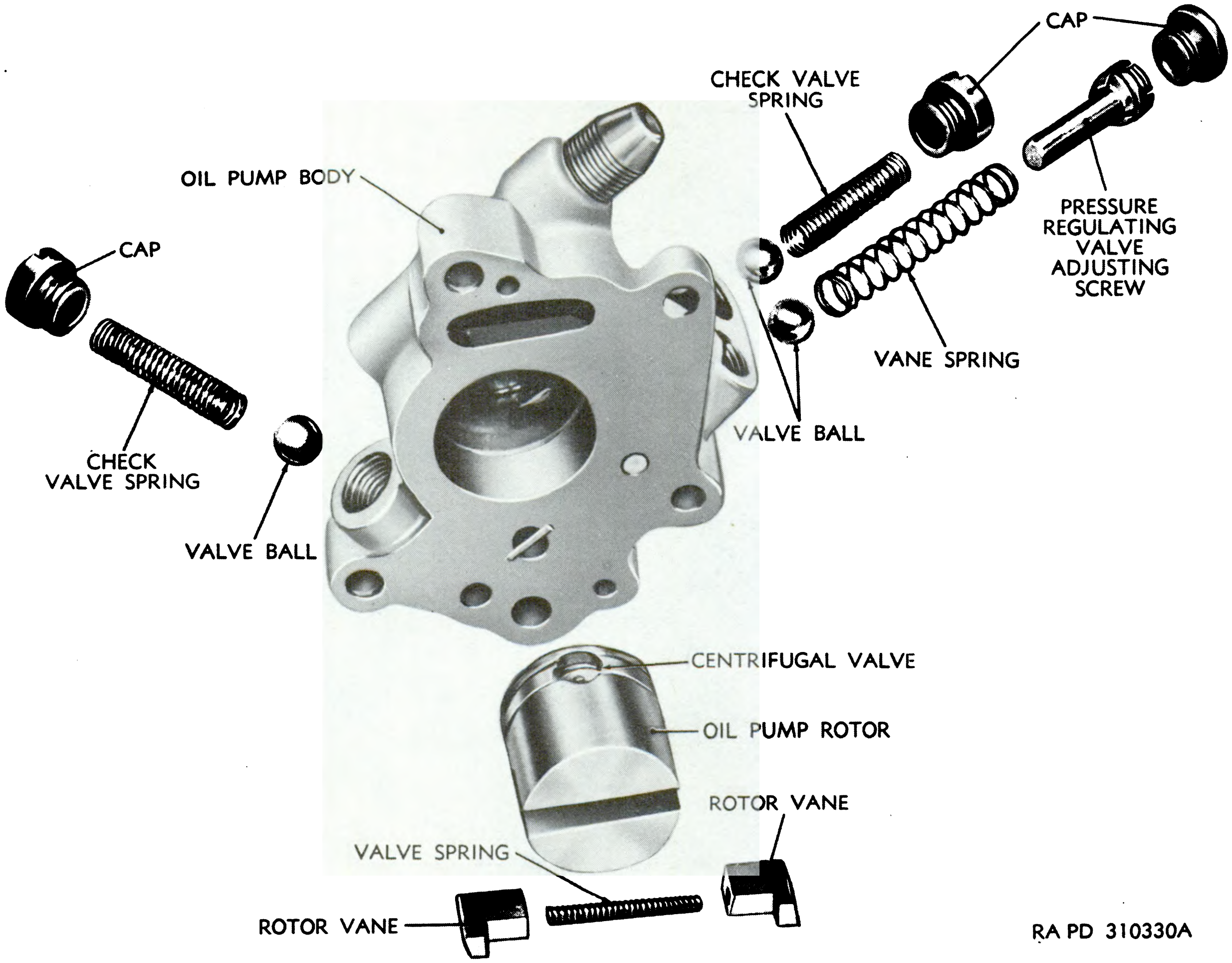

CAP
CHECK VALVE SPRING
OIL PUMP BODY
CAP
PRESSURE REGULATING VALVE ADJUSTING SCREW
VANE SPRING
CHECK VALVE SPRING
VALVE BALL
VALVE BALL
CENTRIFUGAL VALVE
OIL PUMP ROTOR
ROTOR VANE
VALVE SPRING
ROTOR VANE
RA PD 310330A

Figure 632. Oil feed pump—disassembled view.

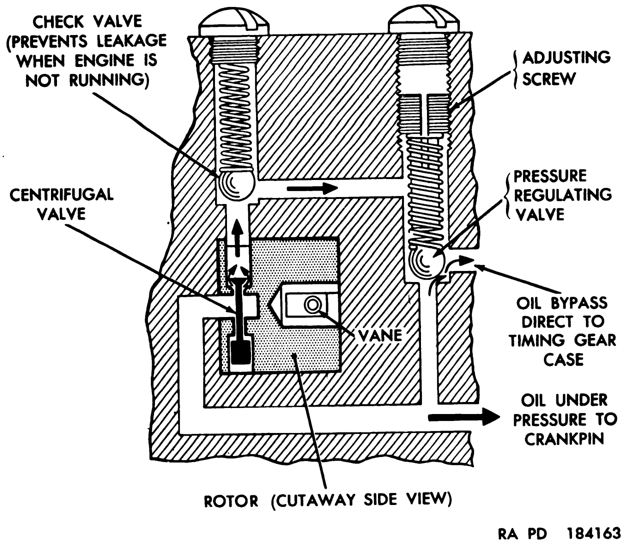

CHECK VALVE (PREVENTS LEAKAGE WHEN ENGINE IS NOT RUNNING)
ADJUSTING SCREW
PRESSURE REGULATING VALVE
CENTRIFUGAL VALVE
OIL BYPASS DIRECT TO TIMING GEAR CASE
VANE
OIL UNDER PRESSURE TO CRANKPIN
ROTOR (CUTAWAY SIDE VIEW)
RA PD 184163

Figure 633. Oil feed pump automatic centrifugal bypass valve—cross sectional view.

and pressure builds up at the feed pump, opening a pressure regulating valve which allows oil to bypass to the timing gear case. The oil lubricates the timing gear train as it drains to the bottom of the case.

(4) The downward motion of the piston forces oil and air out of the crankcase into a large, elongated hole in the hollow breather valve shaft. This shaft is timed so that the elongated breather valve hole registers with a crankcase port hole only when the crankcase is under pressure during the downward strokes of the pistons.

(5) The gear-type scavenger pump (fig. 634), mounted below the timing gear case (fig. 631), is driven by a spiral gear on the timing pinion gear shaft (fig. 629) which

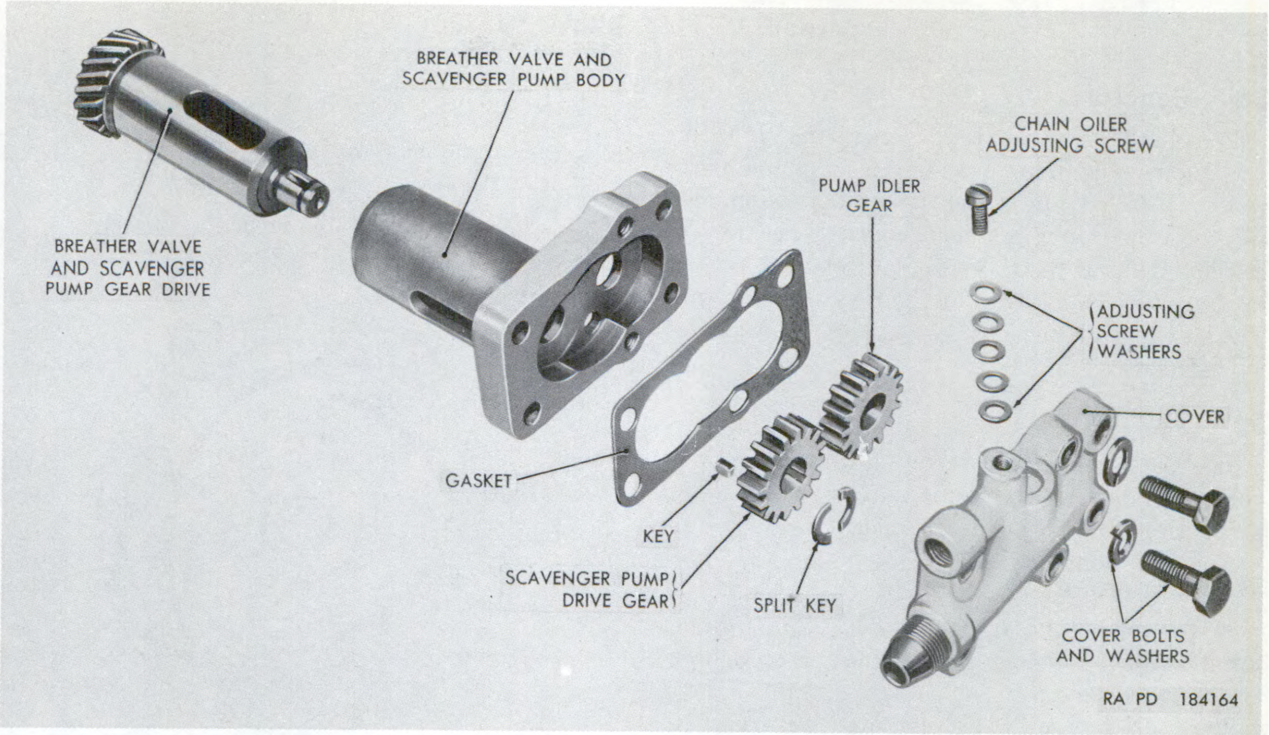

BREATHER VALVE AND SCAVENGER PUMP BODY
CHAIN OILER ADJUSTING SCREW
PUMP IDLER GEAR
BREATHER VALVE AND SCAVENGER PUMP GEAR DRIVE
ADJUSTING SCREW WASHERS
COVER
GASKET
KEY
SCAVENGER PUMP DRIVE GEAR
SPLIT KEY
COVER BOLTS AND WASHERS
RA PD 184164

Figure 634. Oil scavenger pump and breather valve—disassembled view.

also drives the breather valve. The scavenger pump drains the oil from below the timing gear case and forces it under pressure to the oil tank to be recirculated.

356. Kick Starter

The kick starter, or crank, by means of which the engine is cranked by foot for starting, is generally located on the right side of the motorcycle, below the saddle. It is directly connected to the transmission countershaft, or geared to the transmission through a ratchet, in such a manner that a full swing of the crank will rotate the engine several revolutions. A spring is provided to return the crank to the release position as soon as foot pressure is removed.

Section IV. FUEL AND EXHAUST SYSTEMS

357. General

a. The motorcycle fuel system is similar to those used on other automotive vehicles (par. 38) with the one exception that no fuel pump is employed to deliver the fuel from the tanks through the fuel strainer or filter to the carburetor; the fuel is fed by gravity from the tanks to the carburetor.

b. The exhaust system is like that used on other automotive vehicles (par. 56).

358. Fuel Tanks

Motorcycle fuel tanks are made of light gage sheet-metal sections. The tanks are placed on the top frame member, together with the oil tanks. On some models, the reserve fuel tank and oil tank are combined into one unit, with an internal wall or baffle, to separate the two sections.

359. Carburetor and Air Cleaner

a. The carburetors used on motorcycles are generally of the side outlet, plain tube type with a fixed venturi. A float circuit, high-speed circuit, low-speed or idling circuit, and a choke circuit are incorporated (par. 45). The throttle is manually operated by linkage from a lever on a handlebar grip, while the choke is manually operated through a lever on the side of the carburetor.

b. Oil-bath wet-type air cleaners (par. 53), of special shape for motorcycle service, are employed.

360. General

The motorcycle electrical generating, ignition, and lighting systems are similar in principle to those installed on other automotive vehicles. Slight variations are incorporated because of the smaller electrical load requirements and to insure proper operation of the 2-cylinder engine. The single-wire, negative ground return system of wiring is used.

361. Battery

The battery employed on motorcycles is a 6-volt, 29-ampere-hour unit. Construction and principles of operation are described in chapter 10.

362. Generator

a. The principles of the 6-volt, shunt-wound, third-brush-type generator employed on motorcycles are described in paragraph 137. Some models use a lamp-load regulated generator to increase the generator output whenever the lights are turned on.

b. In the lamp-load type third-brush generator, the regulating field coil is connected between the positive brush and the third brush (fig. 635). The shunt-field coil is connected between the negative

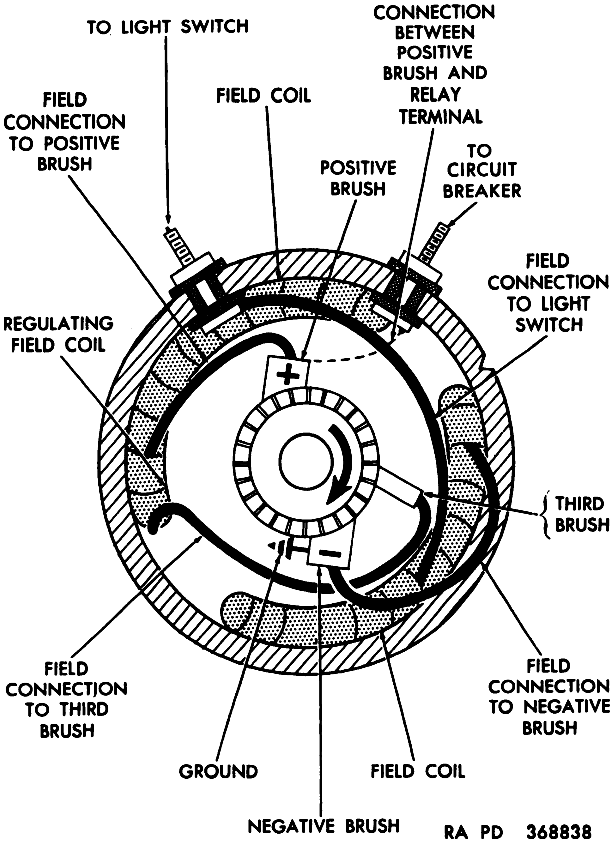

TO LIGHT SWITCH
CONNECTION BETWEEN POSITIVE BRUSH AND RELAY TERMINAL
FIELD CONNECTION TO POSITIVE BRUSH
FIELD COIL
POSITIVE BRUSH
TO CIRCUIT BREAKER
FIELD CONNECTION TO LIGHT SWITCH
REGULATING FIELD COIL
THIRD BRUSH
FIELD CONNECTION TO THIRD BRUSH
GROUND
FIELD COIL
FIELD CONNECTION TO NEGATIVE BRUSH
NEGATIVE BRUSH
RA PD 368838

Figure 635. Lamp-load type third-brush generator.

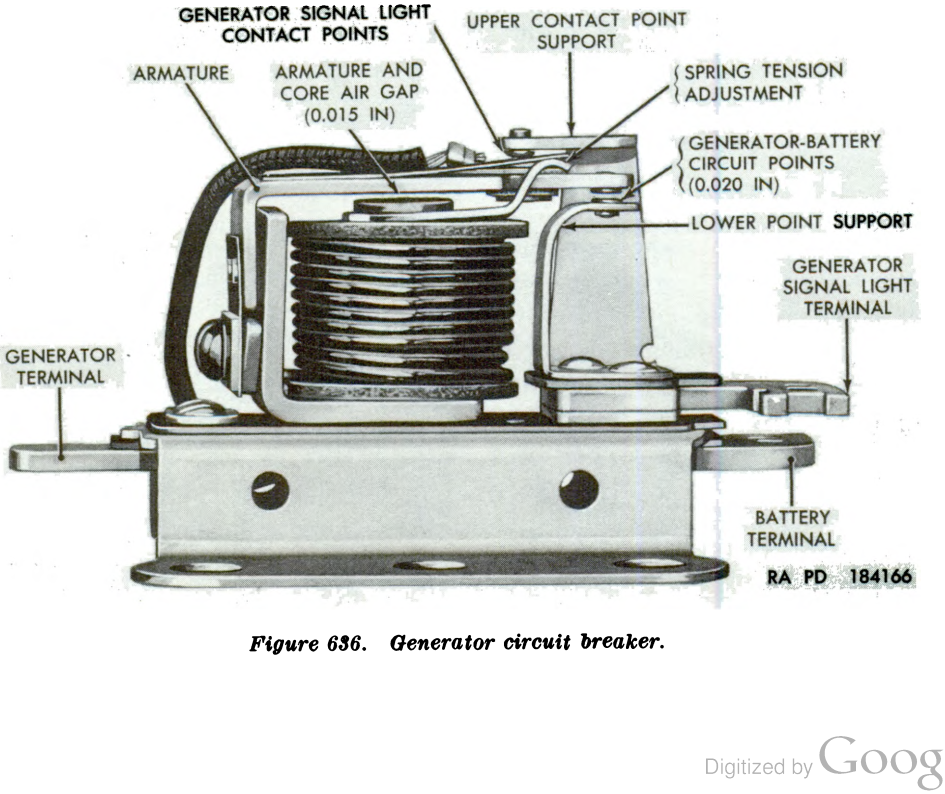

GENERATOR SIGNAL LIGHT CONTACT POINTS
UPPER CONTACT POINT SUPPORT
ARMATURE
ARMATURE AND CORE AIR GAP (0.015 IN)
SPRING TENSION ADJUSTMENT
GENERATOR-BATTERY CIRCUIT POINTS (0.020 IN)
LOWER POINT SUPPORT
GENERATOR SIGNAL LIGHT TERMINAL
GENERATOR TERMINAL
BATTERY TERMINAL
RA PD 184166

Figure 636. Generator circuit breaker.

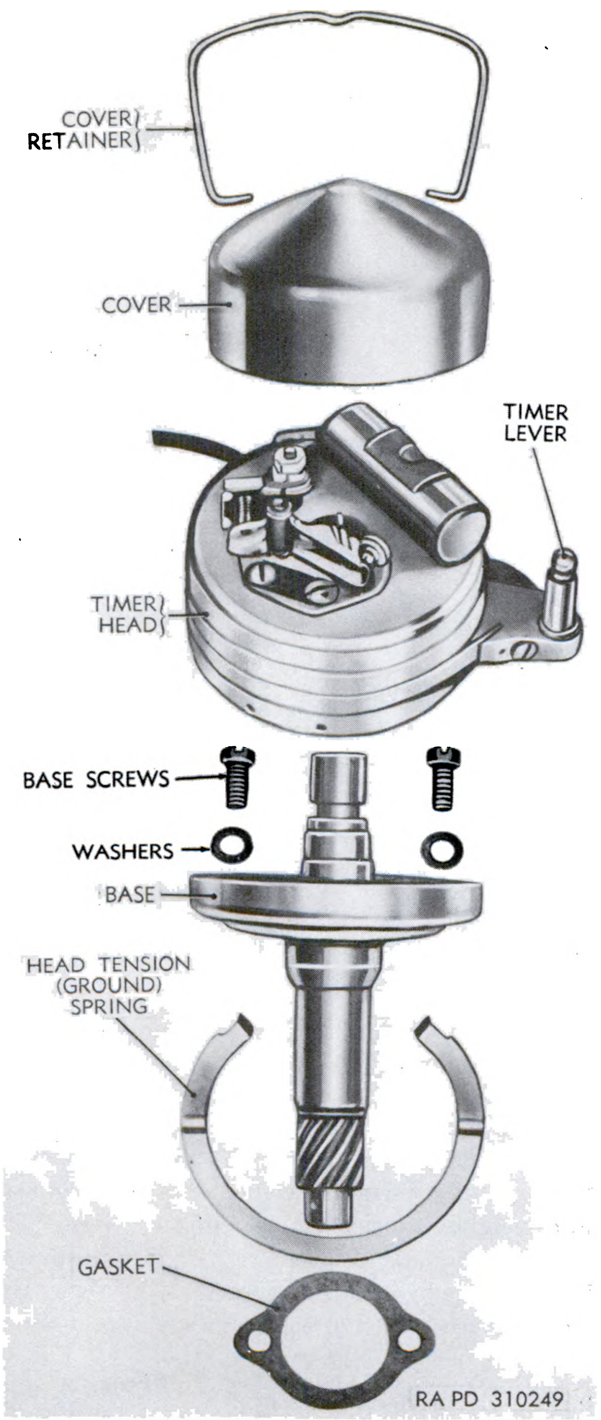


Figure 637. Ignition timer (circuit breaker)—disassembled view.

grounded brush and the light switch terminal. With the light switch off and no current being drawn by the lights, the regulating field coil functions normally, with an output of from 4 to 5 amperes. When the light switch is turned on, the shunt-field coil is in the circuit between the battery and the lights. The current flow to the lights passes through the shunt field, increasing the generator magnetic field, which in turn increases the generator current output. The generator is thereby regulated by the additional current load, causing an increase in generator output.

c. The motorcycle generator is mounted on the engine crankcase, in which case it is gear-driven through the timing gear train; or on the frame, where it is belt- or chain-driven.

363. Circuit Breaker

Reverse-current circuit breaker, such as those installed in the motorcycle generating systems between the generator and battery, are described in paragraph 130. An additional set of contact points (fig. 636), which are in the closed position when the relay main contact points are open, is provided to control a generator signal light on the instrument panel. When generator voltage exceeds battery voltage (6.3 to 6.8 volts), the circuit breaker closes the main-generator-to-battery-circuit by closing the main contact points. The signal light contact points are opened at this time, causing the signal light to go out, indicating that the generator is charging the battery and supplying current for the other electrical loads.

364. Ignition System

a. The motorcycle ignition system is the same as in other automotive vehicles (par. 149) except that on some models a circuit breaker, or timer, is used instead of a distributor. Ignition coils used with the timer are made with two high-tension winding terminals that are directly connected to the two spark plugs. Both sparks plugs fire at the same time. When one cylinder is completing its compression stroke and is ready for firing, the second is on an exhaust stroke (par. 351). Thus, although both spark plugs fire, only one cylinder contains the compressed air-fuel charge for firing, and only that cylinder delivers a power stroke. This method of firing is known as the *waste*, or *double-spark*, type.

b. The ignition system incorporates a 2-spark-plug terminal distributor and operates in the same manner as conventional battery ignition systems.

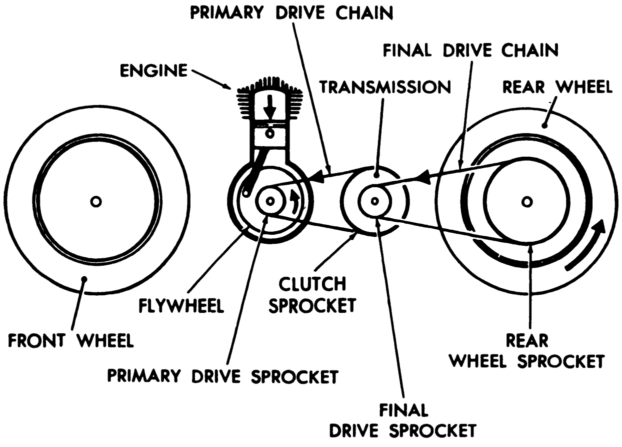
365. Ignition Timer (Circuit Breaker)

The construction of the ignition timer (fig. 637), used for the double-spark system, resembles the breaker units of a conventional distributor. The stationary contact point is grounded, while the breaker arm and movable point are connected through the ignition coil primary winding and through the ignition switch to the battery. The breaker cam is driven through its shaft by a spiral gear on the rear intake valve cam gear. The two cam lobes are so made that the plugs spark at the proper time for each cylinder. During operation, the spark plug timing can be advanced or retarded by a control lever on one of the handle-bar grips. Operating the spark timing control lever causes the timer housing to rotate, repositioning the breaker arm and movable point with respect to the breaker cam.

Section VI. POWER TRAIN

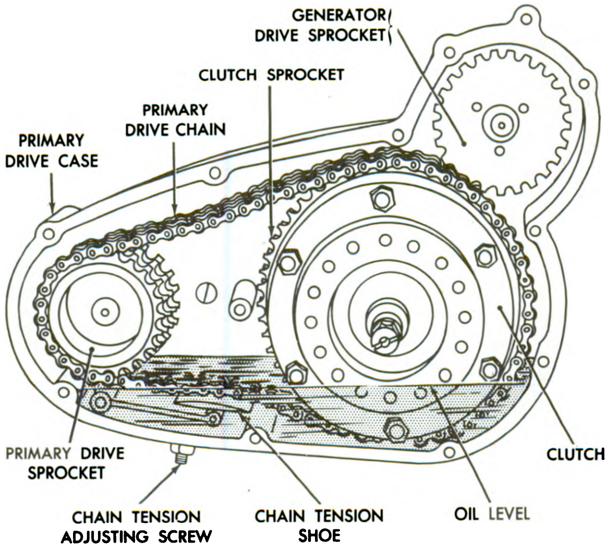
366. General

The power developed by the engine is transmitted to the rear wheel by a power train which consists of a primary drive, clutch, transmission, and final drive (fig. 638). The primary drive sprocket is mounted on the engine flywheel main shaft. As the engine rotates, power is transmitted by the primary drive chain to the clutch sprocket. With the clutch engaged, the power is transmitted through the clutch to the transmission and final-drive sprocket. The final-drive chain connects the final-drive sprocket to the sprocket on the rear wheel. Torque multiplication, and consequent speed reduction between the engine and rear wheel, results from the larger sprocket installed as the driven members of each portion of the power train. A torque increase and speed reduction occurs between the primary drive sprocket on the engine and the clutch sprocket, and a further torque increase and speed reduction occurs between the final-drive sprocket and the rear wheel sprocket. In addition, the various transmission gear ratios provide torque multiplication.


PRIMARY DRIVE CHAIN
FINAL DRIVE CHAIN
ENGINE
TRANSMISSION
REAR WHEEL
FLYWHEEL
CLUTCH SPROCKET
FRONT WHEEL
REAR WHEEL SPROCKET
PRIMARY DRIVE SPROCKET
FINAL DRIVE SPROCKET

RA PD 184167

Figure 638. Motorcycle power train.


GENERATOR DRIVE SPROCKET
CLUTCH SPROCKET
PRIMARY DRIVE CHAIN
PRIMARY DRIVE CASE
PRIMARY DRIVE SPROCKET
CLUTCH
CHAIN TENSION ADJUSTING SCREW
CHAIN TENSION SHOE
OIL LEVEL

RA PD 184168

Figure 639. Wet-type primary drive.

367. Primary Drive

Either wet- or dry-type primary drives are used on motorcycles. The wet type (fig. 639) operates in a bath of oil, while the dry type (fig. 640) operates within a dry case. Lubrication for the primary-drive chain in the dry type is provided through an adjustable needle valve that connects to the engine lubrication system (fig. 631). The chain tension in primary drives is adjusted in some models by means of a variable-height chain-tension shoe which presses against the chain to maintain tension. In other models, chain tension is adjusted by shifting the transmission and clutch.

368. Clutch

a. Motorcycle clutches are of the multiple-disk type whose operating principles are similar to other automotive clutches (par. 191). Plain steel disks and lined disks are set alternately in the clutch housing. The disks of one set are splined or keyed to the clutch sprocket (fig. 641) and act

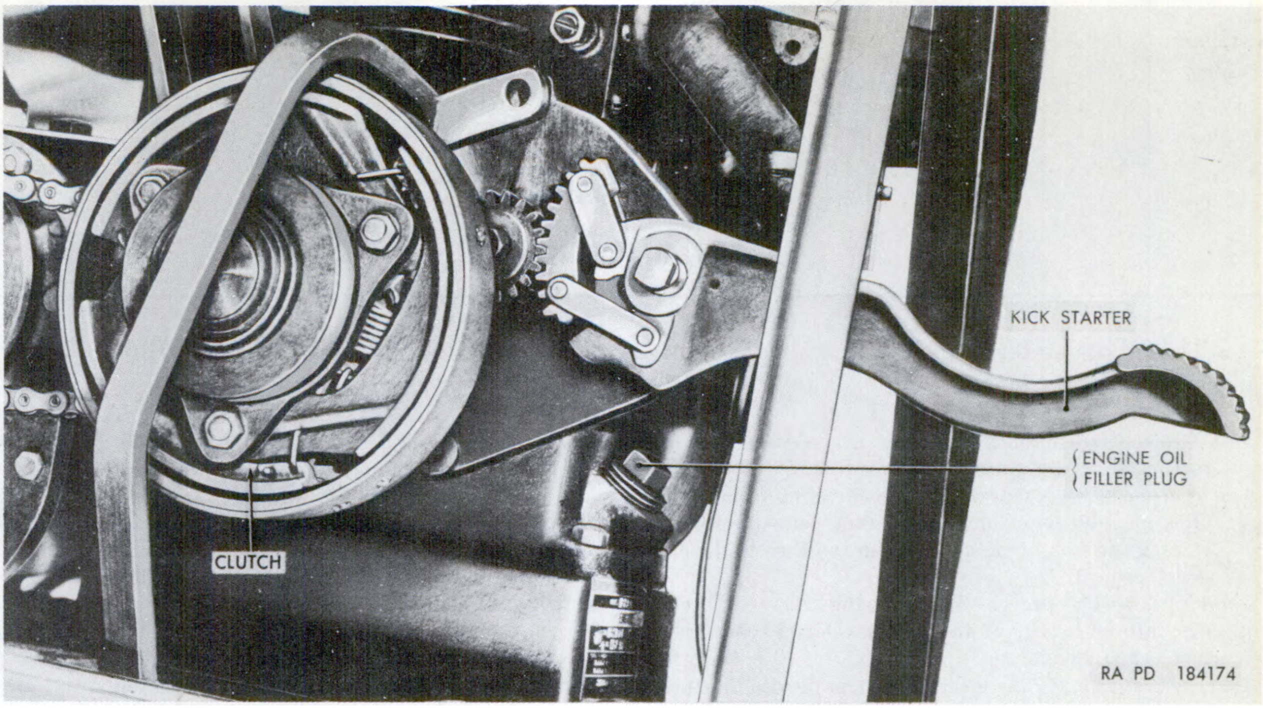

KICK STARTER
ENGINE OIL FILLER PLUG
CLUTCH
RA PD 184174

Figure 649. Kick starter and clutch.

PART EIGHT

TERMINOLOGY

The following terms include all special automotive terms used in TM 9–8000, arranged alphabetically and not by subject matter.

AC—Alternating current, or current that reverses its direction at regular intervals.

Accelerating pump—A device in the carburetor that supplies an additional amount of fuel, temporarily enriching the fuel-air mixture when the throttle is suddenly opened.

Acceleration—The process of increasing velocity. Average rate of change of increasing velocity, usually in feet per second.

Ackerman steering—The steering-system design that permits the front wheels to round a turn without sideslip by turning the inner wheel in more than the outer wheel.

Air bleed—A passage in the carburetor through which air can seep or bleed into fuel moving through a fuel passage.

Air brakes—Vehicle brakes actuated by air pressure.

Air cleaner—A device, mounted on the carburetor or connected to the carburetor, through which air must pass before entering the carburetor air horn. A filtering device in the air cleaner removes dust and dirt particles from the air.

Air-cooled engine—An engine cooled by air circulating between cylinders and around cylinder head as opposed to the liquid-cooled engine cooled by a liquid passing through jackets surrounding the cylinders.

Air filter—A filter through which air passes, and which removes dust and dirt particles from the air. Air filters are placed in passages through which air must pass, as in crankcase breather, air cleaner, etc.

Air horn—That part of the air passage in the carburetor which is on the atmospheric side of the venturi. The choke valve is located in the air horn.

Air-pac brakes—A type of braking system using a vacuum.

Ammeter—An electric meter that measures current, in amperes, in an electric circuit.

Ampere—Unit of electric-current-flow measurement. The current that will flow through a 1-ohm resistance when 1 volt is impressed across the resistance.

Amphibious vehicle—A vehicle with a hull that permits it to float in water, and tracks or wheels that permit it to travel on land.

Angle of approach—The maximum angle of an incline onto which a vehicle can move from a horizontal plane without interference; as, for instance, from front bumpers.

Angle of departure—The maximum angle of an incline from which a vehicle can move onto a horizontal plane without interference; as, for instance, from rear bumpers.

Antifreeze—A substance added to the coolant system in a liquid-cooled-engine to prevent freezing.

Antifriction bearing—A bearing of the type that supports the imposed load on rolling surfaces (balls, rollers, needles), minimizing friction.

Antiknock—Refers to substances that are added to automotive fuel to decrease the tendency to knock when fuel-air mixture is compressed and ignited in the engine cylinder.

Armature—The rotating assembly in a direct current generator or motor. Also, the iron piece in certain electrical apparatus that completes a magnetic (and in many cases, an electric) circuit.

Atmosphere—The mass of air that surrounds the earth.

Atmospheric pressure—The weight of the atmosphere per unit area.

Atom—The smallest particle, or part, of an element, composed of electrons and protons and also of neutrons (with exception of hydrogen).

Atomization—The spraying of a liquid through a nozzle so that the liquid is broken into tiny globules or particles.

Automatic choke—A choke that operates automatically in accordance with certain engine conditions (usually temperature and intake manifold vacuum) (also electrically controlled).

Automatic transmission—A transmission that reduces or eliminates the necessity of handshifting of gears to secure different gear ratios in the transmission.

Axial—In a direction parallel to the axis. Axial movement is movement parallel to the axis.

Axis—A center line. The line about which something rotates or about which something is evenly divided.

Axle—A cross support on a vehicle on which supporting wheel, or wheels, turn. There are two general types: live axles that also transmit power to the wheels and dead axles that transmit no power.

Backfiring—Pre-explosion of fuel-air mixture so that explosion passes back around the opened intake valve and flashes back through the intake manifold.

Backlash—The backward rotation of driven gear that is permitted by clearance between meshing teeth of two gears.

Baffle—A plate or shield to divert the flow of liquid or gas.

Ball bearing—A type of bearing which contains steel balls that roll between inner and outer races.

Battery—A device consisting of two or more cells for converting chemical energy into electrical energy.

Battery charging—The process of supplying a battery with a flow of electric current to produce chemical actions in the battery; these actions reactivate the chemicals in the battery so they can again produce electrical energy.

BDC—Bottom dead center; the position of the piston when it reaches the lower limit of travel in the cylinder.

Bearing—A part in which a journal pivot, or pin turns or revolves. A part on or in which another part slides.

Bendix drive—A type of drive used in a starter which provides automatic coupling with the engine flywheel for cranking and automatic uncoupling when the engine starts.

Bevel gear—One of a pair of meshing gears whose working surfaces are inclined to the center lines of the driving and driven shafts.

Blackout lights—A lamp installed on a vehicle for use during blackouts, which can be seen from the air only at very close range.

Block—*See* Cylinder block.

Blow-by—Leakage of the compressed fuel-air mixture or burned gases from combustion, passing piston and rings and into the crankcase.

Blower—A mechanical device for compressing and delivering air to engine at higher than atmospheric pressure.

Body—The assembly of sheet-metal sections, framework, doors, windows, etc., which provides an enclosure for passengers or carriage space for freight.

Bogie—A suspension unit consisting of tandem axles jointed by a single cross support (trunnion axle) that also acts as a vertical pivot for the entire unit.

Bond—To bind together.

Bore—The diameter of engine cylinder hole. Also diameter of any hole; as, for example, the hole into which a bushing is fitted.

Boss—An extension or strengthened section, such as the projections within a piston which supports the piston pin.

Brake band—A flexible band, usually of metal with an inner lining of brake fabric, which is tightened on a drum to slow or stop drum rotation.

Brakedrum—Metal drum mounted on car wheel or other rotating members; brake shoes or brake band, mechanically forced against it, causes it to slow or stop.

Brake fluid—A compounded fluid used in hydraulic braking system; it transmits hydraulic force from the brake master cylinder to the wheel cylinder and should be impervious to heat or freezing.

Brake lining—A special woven fabric material with which brake shoes or brake bands are lined: it withstands high temperatures and pressures.

Brakeshoes—The curved metal part, faced with brake lining, which is forced against the brake drum to produce braking or retarding action.

Brake system—The system on a vehicle that slows or stops it as a pedal or lever is operated.

Brake horsepower—The power actually delivered by the engine which is available for driving the vehicle.

Brakes—The mechanism that slows or stops a vehicle or mechanism when a pedal or other control is operated. Also called the *brake system.*

Bronze—An alloy consisting essentially of copper and tin.

Brushes—The carbon or carbon and metal parts in a motor or generator that contact the rotating armature commutator or rings.

Bushing—A sleeve placed in a bore to serve as a bearing surface.

Bypass—A separate passage which permits a liquid, gas, or electric current to take a path other than that normally used.

Cab—Separate driver's compartment provided on trucks.

Cam—A moving part of an irregular form designed to move or alter the motion of another part.

Camber—To curve or bend; the amount in inches or degrees that the front wheels of an automotive vehicle are tilted from a true vertical at the top.

Capacitance—That property of a circuit which tends to increase the amount of current flowing in a circuit for a given voltage or to delete in its entirety.

Capacitor (*condenser*)—A device for inserting the property of capacitance into a circuit; two or more conductors separated by a dielectric.

Carbon-pile regulator—A type of regulator for regulating or controlling voltage or amperage in a circuit, which makes use of a stack, or pile, of carbon disks.

Carburetor—The device in a fuel system which mixes fuel and air and delivers the combustible mixture to the intake manifold.

Caster—The amount in degrees that the steering knuckle pivots are tilted forward or backward from a true vertical.

Cell—A combination of electrodes and electrolyte which converts chemical energy into electrical energy. Two or more cells connected together form a battery.

Centrifugal advance—The mechanism in an ignition distributor by which the spark is advanced or retarded as the engine speed varies.

Centrifugal force—The force acting on a rotating body, which tends to move its parts outward and away from the center of rotation.

Charge indicator—The device on a vehicle that indicates, by a needle, whether or not the battery is receiving a charge from the generator.

Charging rate—The rate of flow, in amperes, of electric current flowing through a battery while it is being charged.

Chassis—An assembly of mechanisms, attached to a frame, that make up the major operating part of an automotive vehicle (less body).

Choke—A device in the carburetor that chokes off, or reduces, the flow of air into the intake manifold; this produces a partial vacuum in the intake manifold and a consequent richer fuel-air mixture.

Circuit—A closed path or combination of paths through which passage of the medium (electric current, air, liquid, etc.) is possible.

Circuit breaker—In electric circuits, a mechanism designed to break or open the circuit when certain conditions exist; especially the device in automotive circuits that opens the circuit between the generator and battery to prevent overcharging of the battery. (One of the three units comprising a generator regulator.)

Clockwise—Direction of movement, usually rotary, which is the same as movement of hands on the face of a clock.

Clutch—The mechanism in an automotive vehicle, located in the power train, that connects the engine to, or disconnects the engine from, the remainder of the power train.

Coil—In electrical circuits, turns of wire, usually on a core and enclosed in a case, through which electric current passes.

Coil spring—A type of spring made of an elastic metal such as steel, formed into a wire or bar and wound into a coil.

Combat vehicle—A type of vehicle, usually armored, for use in armed combat.

Combustion—A chemical action, or burning; in an engine, the burning of a fuel-air mixture in the combustion chamber.

Combustion chamber—The space at the top of the cylinder and in the head in which combustion of the fuel-air mixture takes place.

Commutation—The process of converting alternating current which flows in the armature windings of direct current generators into direct current.

Commutator—That part of rotating machinery which makes electrical contact with the brushes and connects the armature windings with the external circuit.

Compression—Act of pressing into a smaller space or reducing in size or volume by pressure.

Compression ratio—The ratio between the volume in the cylinder with the piston at bottom dead center and with the piston at top dead center.

Compression rings—The upper rings on a piston; the rings designed to hold the compression in the cylinder and prevent blow-by.

Compression stroke—The piston stroke from bottom dead center to top dead center during which both valves are closed and the gases in the cylinder are compressed.

Concentric—Having a common center, as circles or spheres, one within the other.

Condenser—*See* Capacitor.

Conductor—A material through which electricity will readily flow.

Conecting rod—Linkage between the crankshaft and piston, usually attached to the piston by a piston pin and to the crank journal on the crankshaft by a split bearing and bearing cap.

Coolant—The liquid that circulates in an engine cooling system which reduces heat generated by the engine.

Cooling fan—The fan in the engine cooling system that provides a forced circulation of air through the radiator or around the engine cylinders so that cooling is effected.

Cooling fins—Thin metal projections on air-cooled-engine cylinder and head which greatly increases the heat-radiating surfaces and helps provide cooling of engine cylinder.

Cooling system—A system which reduces heat generated by the engine and thereby prevents engine overheating; includes, in liquid cooled engine, engine water jackets, radiator, and water pump.

Core—An iron mass, generally the central portion of a coil or electromagnet or armature around which the wire is coiled.

Counterclockwise—Direction of movement, usually rotary, which is opposite in direction to movement of hands on the face of a clock.

Cowl—The front portion of the vehicle body or cab which partially incloses the dash panel and forms the windshield frame.

Crank—A device for converting reciprocating motion into rotary motion, and vice versa.

Crankcase—The lower part of the engine in which the crankshaft rotates. In automotive practice, the upper part is lower section of cylinder block while lower section is the oil pan.

Crankcase breather—The opening or tube that allows air to enter the crankcase and thus permit crankcase ventilation.

Crankcase dilution—Dilution of the lubricating oil in the oil pan by liquid gasoline seeping down the cylinder walls past the piston rings.

Crankcase ventilation—The circulation of air through the crankcase which removes water and other vapors, thereby preventing the formation of water sludge and other unwanted substances.

Cranking motor—*See* Starter.

Crankshaft—The main rotating member or shaft of the engine, with cranks to which the connecting rods are attached.

Cross-drive transmission—A special type of transmission used in tanks and other heavy vehicles which combines the actions of a transmission with torque converter, steering system, and differential.

Current regulator—A magnetic-controlled relay by which the field circuit of the generator is made and broken very rapidly to secure even current output from the generator and prevent generator overload from excessive output. (One of the three units comprising a generator regulator.)

Cutout relay—An automatic magnetic switch attached to the generator to cut out generator circuit and prevent overcharging of battery. *See* Circuit breaker.

Cycle—A series of events with a start and finish, during which a definite train of events takes place. In the engine, the four piston strokes (or two piston strokes on 2-stroke cycle engine) that complete the working process and produce power.

Cylinder—A tubular-shaped structure. In the engine, the tubular opening in which the piston moves up and down.

Cylinder block—That part of an engine to which, and in which, other engine parts and accessories are attached or assembled.

Cylinder head—The part of the engine that encloses the cylinder bores. Contains water jackets (on liquid-cooled engine) and valves (on I-head engines).

Dc—Direct current, or current that flows in one direction only.

Damper—A device for reducing the motion or oscillations of moving parts, air, or liquid.

Dash panel—The partition that separates the driver's compartment from the engine compartment. Sometimes called firewall.

Dead axle—An axle that simply supports and does not turn or deliver power to the wheel or rotating member.

Deceleration—The process of slowing down. Opposite to acceleration.

Degasser—A device used in connection with carburetors for shutting off the flow of fuel during deceleration so that gases from incomplete combustion during deceleration are prevented.

Detonation—In the engine, excessively rapid burning of the compressed fuel-air mixture so that knocking results.

Diaphragm—A flexible membrane, usually made of fabric and rubber in automotive components, clamped at the edges and usually spring-loaded; used in fuel pump, vacuum pump, distributor, etc.

Diesel engine—An engine using the diesel cycle of operation; air alone is compressed and diesel fuel is injected at the end of the compression stroke. Heat of compression produces ignition.

Differential—A mechanism between axles that permits one axle to turn at a different speed than the other and, at the same time, transmits power from the driving shaft to the axles.

Differential winding—In electrical machinery, a winding that is wound in a reverse direction or different direction than the main operating windings. The differential winding acts to modify or change the action of the machine under certain conditions.

Disk brake—A type of brake which depends upon contact between two or more disks for its effect. One or more of the disks may be faced with brake lining.

Distributor—*See* Ignition distributor.

Dolly—A two-wheel trailer coupled to a semitrailer to support and steer its front end when it is converted into a full trailer.

Drag link—An intermediate link in the steering system between the Pitman arm and an intermediate arm, or drag-link arm.

Dual ignition—Ignition system using two spark plugs for each cylinder so that a dual spark effect takes place driving each power stroke.

Dual-ratio axles—Axle in truck which contains a mechanism for changing driving ratio of the wheels to either high or low ratio. Two-speed differential.

Dynamometer—A device for measuring power output of an engine.

Eccentric—Offcenter.

Eddy currents—Currents which are induced in an iron core and circulate in the core.

Efficiency—Ratio between the effect produced and the power expended to produce the effect.

Electric brakes—A brake system which uses electric current for energization.

Electrical system—In the automotive vehicle, the system that electrically cranks the engine for starting, furnishes high-voltage sparks to the engine cylinders to fire compressed fuel-air charges, lights the lights, operates heater motor, radio, etc. Consists, in part, of starter, wiring, battery, generator, generator regulator, ignition distributor, and ignition coil.

Electricity—A form of energy that involves the movement of electrons from one place to another, or the gathering of electrons in one area.

Electrode—Either terminal of an electric source: either conductor by which the current enters and leaves an electrolyte.

Electrolyte—The liquid in a battery or other electrochemical device, in which the conduction of electricity is accompanied by chemical decomposition.

Electromagnet—Temporary magnet constructed by winding a number of turns of insulated wire into a coil or around an iron core; it is energized by a flow of electric current through the coil.

Electron—Negative charged particle that is a basic constituent of matter and electricity. Movement of electrons is an electric current.

Energy—The capacity for performing work.

Engine—An assembly that burns fuel to produce power, sometimes referred to as the power plant.

Evaporation—The action that takes place when a liquid changes to a vapor or gas.

Exhaust manifold—That part of the engine that provides a series of passages through which burned gases from the engine cylinders may flow to the muffler.

Exhaust stroke—The piston stroke from bottom dead center to top dead center during which the exhaust valve is opened so that burned gases are forced from the engine cylinder.

Exhaust valve—The valve which opens to allow the burned gases to escape from the cylinder during the exhaust stroke.

Fan—*See* Cooling fan.

F-head—A type of engine with valves arranged to form an "F;" one valve is in the head, the other in the cylinder block.

Field—In a generator or electric motor the area in which a magnetic flow occurs.

Field coil—A coil of wire, wound around an iron core, which produces the magnetic field in a generator or motor when current passes through it.

Field frame—The frame in a generator or motor into which the field coils are assembled.

Field winding—*See* Field coil.

Fifth wheel—The flat, round heavy steel plates (upper and lower) together with a kingpin for coupling semitrailer to truck-tractor. The lower plate is mounted on the truck-tractor, the upper on the semitrailer.

Filter—A devise through which gas or liquid is passed; dirt, dust, and other impurities are removed by the separating action.

Final drive—That part of the power train on tractors, truck-tractors tanks, and tank-like vehicles that carries the driving power to the wheels or sprockets to produce the vehicle motion as they turn.

Float—In the carburetor, the metal shell that is suspended by the fuel in the float bowl and controls a needle valve that regulates the fuel level in the bowl.

Float circuit—In the carburetor, the circuit that controls entry of fuel and fuel level in the float bowl.

Fluid coupling—A coupling in the power train that connects between the engine and other power train members through a fluid.

Flywheel—The rotating metal wheel, attached to the crankshaft, that helps level out the power surges from the power strokes and also serves as part of the clutch and engine-cranking system.

Foot-pound—A unit of work done in raising 1 pound avoirdupois against the force of gravity to the height of 1 foot.

Force—The action that one body may exert upon another to change its motion or shape.

Four-stroke-cycle engine—An engine that requires four piston strokes (intake, compression, power, exhaust) to make the complete cycle of events in the engine cylinder.

Frame—An assembly of metal structural parts and channel sections that support the engine and body and that is supported by the vehicle wheels.

Frequency—The number of vibrations, cycles, or changes in direction in a unit of time.

Friction—The resistance to motion between two bodies in contact with each other.

Fuel—The substance that is burned to produce heat and create motion of the piston on the power stroke in an engine.

Fuel filter—A device placed in the fuel line of the fuel system to remove dirt and other harmful solids.

Fuel gage—An indicating device in the fuel system that indicates the amount of fuel in the fuel tank.

Fuel line—The tube or tubes connecting the fuel tank and the carburetor and through which the fuel passes.

Fuel passage—Drilled holes in the carburetor body and tubes through which fuel passes from the float bowl to the fuel nozzles.

Fuel pump—The mechanism in the fuel system that transfers fuel from the fuel tank to the carburetor.

Fuel tank—The storage tank for fuel on the vehicle.

Fulcrum—The support, as a wedge-shaped piece or a hinge, about which a lever turns.

Full trailer—An independent and fully contained vehicle without motive power.

Fuse—A circuit-protecting device which makes use of a substance that has a low melting point. The substance melts if an overload occurs, thus protecting other devices in the system.

Gasket—A flat strip, usually of cork or metal, or both, placed between two surfaces to provide a tight seal between them.

Gasoline—A hydrocarbon, obtained from petroleum, is suitable as an internal combustion engine fuel.

Gear ratio—The relative speeds at which two gears turn; the proportional rate of rotation.

Gears—Mechanical devices to transmit power or turning effort, from one shaft to another; more specifically, gears which contain teeth that engage or mesh upon turning.

Gearshift—A mechanism by which the gears in a transmission system are engaged.

Generator—In the electrical system, the device that changes mechanical energy to electrical energy for lighting lights, charging the battery, etc.

Generator regulator—In the electrical system, the unit which is composed of the current regulator voltage regulator, and circuit breaker relay.

Governor—A mechanism that controls speed or other variable. Specifically, speed governors used on automotive vehicles to prevent excessive engine speed by controlling actions in the carburetor.

Ground—Connection of an electrical unit to the engine or frame to return the current to its source.

Gusset plate—A plate at the joint of a frame structure of steel to strengthen the joint.

Half track—A vehicle using tracks instead of wheels at the rear.

Handbrake—A brake operated by hand. Also referred to as the parking brake.

Headlight—Lights at the front of the vehicle designed to illuminate the road ahead when the vehicle is traveling forward.

Heat—A form of energy.

Helical—In the shape of a helix, which is the shape of a screw thread or coil spring.

High-speed circuit—In the carburetor, the passages through which fuel flows when the throttle valve is fully opened.

High tension—Another term for high voltage. In the electrical system, refers to the ignition secondary circuit since this circuit produces high-voltage surges to cause sparking at the spark plugs.

Hill holder—A device in the transmission that automatically prevents the vehicle from rolling backwards down a hill when the vehicle is brought to a stop.

Horn—An electrical signaling device on the vehicle.

Horsepower—A measure of a definite amount of power; 550 foot-pound per second.

Hotchkiss drive—Type of rear live axle suspension in which the springs serve as torque members.

Hull—In a tank, the protective shell that encloses the vehicle components and occupants.

Hydraulic brakes—A braking system that uses a fluid to transmit hydraulic pressure from a master cylinder to wheel cylinders, which then cause brakeshoe movement and braking action.

Hydraulic steering—A steering sysem that uses a fluid to produce an assisting hydraulic pressure on the steering linkage, thus reducing the steering effort on the part of the driver.

Hydraulic traversing mechanism—A turret traversing system that makes use of hydraulic pressure to furnish the motive power to traverse the turret.

Hydraulic valve tappet—A valve tappet that, by means of hydraulic pressure, maintains zero valve clearance so that valve noise is reduced.

Hydramatic—A type of automatic transmission containing a fluid coupling and automatic controls for shifting from one gear ratio to another.

Hydrometer—A device to determine the specific gravity of a liquid. This indicates the freezing point of the coolant in a cooling system or, as another example, the state of charge of a battery.

Hydrovac brakes—A type of braking system using vacuum to assist in brake operation. The vacuum action reduces the effort required from the driver to operate the vehicle brakes.

Idle—Engine speed when accelerator pedal is fully released; generally assumed to mean when engine is doing no work.

Idle circuit—The circuit in the carburetor through which fuel is fed when the engine is idling.

Idler gear—A gear placed between a driving and a driven gear to make them rotate in the same direction. It does not affect the gear ratio.

Idling adjustment—Adjustment made on the carburetor to alter the fuel-air mixture ratio or engine speed on idle.

Ignition—The action of setting fire to; in the engine, the initiating of the combustion process in the engine cylinders.

Ignition advance—Refers to the spark advance produced by the distributor in accordance with engine speed and intake manifold vacuum.

Ignition coil—That component of the ignition system that acts as a transformer and steps up battery voltage to many thousand volts; the high voltage then produces a spark at the spark-plug gap.

Ignition distributor—That component of the ignition system that closes and opens the circuit between the battery and ignition coil, and distributes the resultant high-voltage surges from the coil to the proper spark plugs.

Ignition switch—The switch in the ignition system that can be operated to open or close the ignition primary circuit.

Ignition timing—Refers to the timing of the spark at the spark plug as related to the piston position in the engine cylinder.

I-head—A type of engine with valves in the cylinder head.

Impeller—The rotor of a centrifugal pump which causes the fuel-air in an engine to be thrown into a diffuser chamber to effect thorough mixing and good distribution.

Indicated horsepower—A measurement of engine power based on power actually developed in the engine cylinders.

Induction—The action or process of producing voltage by the relative motion of a magnetic field and a conductor.

Injector—The mechanism, including nozzle, which injects fuel into the engine combustion chamber on diesel engines.

In-line engine—An engine in which all engine cylinders are in a single row, or line.

Insert—A form of screw thread insert to be placed in a tapped hole into which a screw or bolt will be screwed. The insert protects the part into which the hole was tapped, preventing enlargement due to repeated removal and replacement of the bolt.

Insulation—Substance that stops movement of electricity (electrical insulation) or heat (heat insulation).

Insulator—A substance (usually of glass or porcelain) that will not conduct electricity.

Intake manifold—That component of the engine which provides a series of passages from the carburetor to the engine cylinders through which fuel-air mixture can flow.

Intake stroke—The piston stroke from top dead center to bottom dead center during which the intake valve is open and the cylinder receives a charge of fuel-air mixture.

Intake valve—The valve in the engine which is opened during the intake stroke to permit the entrance of fuel-air mixture into the cylinder.

Integral—Whole; entire; lacking nothing of completeness.

Interference—In radio, any signal received that overrides or prevents normal reception of the desired signal. In mechanical practice, anything that causes mismating of parts so they cannot be normally assembled.

Internal combustion engine—An engine in which the fuel is burned inside the engine, as opposed to an external combustion engine where the fuel is burned outside the engine, such as a steam engine.

Internal gear—A gear in which the teeth point inward rather than outward as with a standard spur gear.

Jackshaft—An intermediate driving shaft.

Jet—A metered opening in an air or fuel passage to control the flow of fuel or air.

Journal—That part of a shaft that rotates in a bearing.

Kingpin—The pin by which a stud axle is articulated to an axle-beam or steering head; also the enmeshing pin in a fifth wheel assembly.

Kingpin inclination—The number of degrees that the kingpin, which supports the front wheel, is tilted from the vertical.

Knock—In the engine, a rapping or hammering noise resulting from excessively rapid burning or detonation of the compressed fuel-air mixture.

Knuckle—A joint or parts carrying a hinge pin which permit one part to swing about or move in relation to another.

Laminated—Made up of thin sheets, leaves, or plates.

Laminated leaf spring—Spring made up of leaves of graduated size.

Landing gear—Retractable support under the front end of a semitrailer to hold it up when it is uncoupled from the truck tractor.

Lean mixture—A fuel-air mixture that has a high proportion of air and a low proportion of fuel.

Lever—A rigid bar or beam of any shape capable of turning about one point, called the fulcrum; used for transmitting or changing force or motion.

Leverage—The mechanical advantage obtained by use of lever; also an arrangement or combination of levers.

L-head—A type of engine with valves in the cylinder block.

Light—In the electric circuit, an electrical device that includes a wire in a gas-filled bulb which glows brightly when current passes through it—often called a lamp.

Lighting switch—In the electrical circuit, a switch that turns light on or off.

Lubrication—The process of supplying a coating of oil between moving surfaces to prevent actual contact between them. The oil film permits relative movement with little frictional resistance.

Lunette—An eye that hooks into a pintle assembly to tow vehicles.

Magnet—Any body that has the ability to attract iron.

Magnetic field—The space around a magnet which the magnetic lines of force permeate.

Magnetic flux—The total amount of magnetic induction across or through a given surface.

Magnetic pole—Focus of magnetic lines of force entering or emanating from magnet.

Magnetism—The property exhibited by certain substances and produced by electron (or electric current) motion which results in the attraction of iron.

Magneto—A device that generates voltage surges, transforms them to high-voltage surges, and distributes them to the engine cylinder spark plugs.

Main bearing—In the engine, the bearings that support the crankshaft.

Manifold—*See* Intake manifold or exhaust manifold.

Master cylinder—In the hydraulic braking system, the liquid-filled cylinder in which hydraulic pressure is developed by depression of the brake pedal.

Master rod—In a radial engine, the rod to which all other connecting rods are attached, or articulated.

Matter—Anything which has weight and occupies space.

Mechanical efficiency—In an engine, the ratio between brake horsepower and indicated horsepower.

Mechanism—A system of parts or appliances which acts as a working agency to achieve a desired result.

Member—Any essential part of a machine or structure.

Meshing—The mating or engaging of the teeth of two gears.

Metering rod—A small rod, having a varied diameter, operated within a jet to vary the flow of fuel through the jet.

Molecule—The smallest particle into which a chemical compound can be divided.

Motor—A device for converting electrical energy into mechanical energy.

Motorcycle—Two-wheeled vehicle similar to a bicycle but motor-driven.

Motor tricycle—Similar to a motorcycle except the rear wheel has been replaced by two wheels.

Muffler—In the exhaust system, a device through which the exhaust gases must pass; in the muffler, the exhaust sounds are greatly reduced.

Mutual induction—Induction associated with more than one circuit, as two coils, one of which induces current in the other as the current in the first changes.

Negative—A term designating the point of lower potential when the potential difference between two points is considered.

Negative terminal—The terminal from which electrons depart when a circuit is completed from this terminal to the positive terminal of generator or battery.

Needle valve—Type of valve with rod-shaped, needle-pointed valve body which works into a valve seat so shaped that the needle point fits into it and closes the passage; the needle valve in the carburetor float circuit is an example.

North pole—The pole of a magnet from which the lines of force are assumed to emanate.

No-spin differential—A special type of differential which prevents the spinning of one of the driving wheels even if it is resting on smooth ice.

Nozzle—An orifice or opening in a carburetor through which fuel feeds into the passing air stream on its way to the intake manifold.

Octane rating—A measure of the antiknock value of engine fuel.

Odometer—The part of the speedomter that measures, accumulatively, the number of vehicle miles traveled.

Ohm—A measure of electrical resistance. A conductor of one ohm resistance will allow a flow of one ampere of current when one volt is imposed on it.

Ohmmeter—A device for measuring ohms resistance of a circuit or electrical machine.

Oil—A liquid lubricant derived from petroleum and used in machinery to provide lubrication between moving parts. Also, fuel used in diesel engines.

Oil control rings—The lower rings on the piston which are designed to prevent excessive amounts of oil from working up into the combustion chamber.

Oil cooler—A special cooling radiator, through which hot oil passes. Air also passes through separate passages in the radiator, providing cooling of the oil.

Oil gage—Indicating device that indicates the pressure of the oil in the lubrication system. Also a bayonet-type rod to measure oil in the crankcase.

Oil pan—The lower part of the crankcase in which a reservoir of oil is maintained.

Oil pump—The pump that transfers oil from the oil pan to the various moving parts in the engine that require lubrication.

Oil strainer—A strainer placed at the inlet end of the oil pump to strain out dirt and other particles, preventing these from getting into moving engine parts.

Overflow tank—Special tank in cooling system (a surge tank) for hot or dry country to permit expansion and contraction of engine coolant without loss.

Overhead valve—Valve mounted in head above combustion chamber. Valve in I-head engine.

Overload breaker—In an electrical circuit, a device that breaks or opens a circuit if it is overloaded by a short, ground, use of too much equipment, etc.

Overrunning clutch—A type of drive mechanism used in a starter which transmits cranking effort but overruns freely when engine tries to drive starter. Also, a special clutch used in several mechanism that permits a rotating member to turn freely under some conditions but not under other conditions.

Parabolic reflector—A reflector that sends all reflected light originating at the focal point outward in parallel rays.

Parallel circuit—The electrical circuit formed when two or more electrical devices have like terminals connected together (positive to positive and negative to negative) so that each may operate independently of the other.

Parking brake—*See* Handbrake.

Period—The time required for the completion of one cycle.

Permanent magnet—Piece of steel or alloy in which molecules are so alined that the piece continues to exhibit magnetism without application of external influence.

Phase—That portion of a whole period which has elapsed since the activity in question passed through zero position in a positive direction.

Pilot—A short plug at the end of a shaft to aline it with another shaft or rotating part.

Pinion—The smaller of two mating or meshing gears.

Pintle assembly—A swivel-type assembly used to engage with a lunette for towing trailers.

Piston—In an engine, the cylindrical part that moves up and down in the cylinder.

Piston displacement—The volume displaced by the piston as it moves from the bottom to the top of the cylinder in one complete stroke.

Piston pin—The cylindrical or tubular metal pin that attaches the piston to the connecting rod (also called wrist pin).

Piston ring—One of the rings fitted into grooves in the piston. There are two types, compression rings and oil-control rings.

Piston rod—*See* Connecting rod.

Pitman arm—The arm that is a part of the steering gear; it is connected by linkage to the wheel steering knuckle.

Pivot inclination—*See* Kingpin inclination.

Planetary gears—Set of gears that includes a central spur gear, called the sun gear, around which revolves one or more meshing planetary gears. An internal gear, meshed with the planetary gears, completes the set.

Poppet—A spring-loaded ball engaging a notch. A ball latch.

Positive—A term designating the point of higher potential when the potential difference between two points is considered.

Potential—A characteristic of a point in an electric field or circuit indicated by the work necessary to bring a unit positive charge from infinity; the degree of electrification as compared to some standard (the earth, for example).

Potential difference—The arithmetical difference between two electrical potentials; same as electromotive force, electrical pressure, or voltage.

Power—The rate of doing work.

Power divider—A mechanism placed between dual rear axles to apportion driving effort between the two pairs of wheels to provide the maximum tractive effort.

Power plant—The engine or power-producing mechanism on the vehicle.

Power steering—Vehicle steering by use of hydraulic pressure to multiply the driver's steering effort so as to improve ease of steering.

Power stroke—The piston stroke from top dead center to bottom dead center during which the fuel-air mixture burns and forces the piston down so the engine produces power.

Power-take-off—An attachment for connecting the engine to power driven auxiliary machinery when its use is required.

Preignition—Premature ignition of the fuel-air mixture being compressed in the cylinder on the compression stroke.

Primer—An auxiliary fuel pump operated by hand to feed additional fuel into the engine to produce a richer mixture for starting.

Prismatic lens—A lens with parallel grooves or flutes which deflect and distribute light rays.

Propeller shaft—The driving shaft in the power train that carries engine power from the transmission to the differential; also, the shaft that turns the propeller in amphibian vehicles.

Proton—Basic particle of matter having a positive electrical charge, normally associated with the nucleus of the atom.

Psi—Pounds per square inch, a measure of force per unit area.

Pump—A device that transfers gas or liquid from one place to another.

Rpm—Revolutions per minute, a measure of rotational speed.

Radial—Pertaining to the radius of a circle.

Radial engine—An engine with each cylinder located on the radius of a circle and with all cylinders disposed around a common crankshaft.

Radiator—A device in the cooling system that removes heat from the coolant passing through it, permitting coolant to remove heat from the engine.

Radius—Distance from the center of a circle or from center of rotation.

Rectifier—An electrical device that changes alternating current to direct current.

Relay—In the electrical system, a device that opens or closes a second circuit in response to voltage or amperage changes in a controlling circuit.

Residual magnetism—The magnetism retained by a material after all magnetizing forces have been removed.

Resistance—The opposition offered by a substance or body to the passage through it of an electric current.

Resistor—In an electrical system, a device made of resistance wire, carbon, or other resisting material, which has a definite value of resistance and serves a definite purpose in the system by virtue of that resistance.

Rheostat—A resistor for regulating the current by means of variable resistance.

Rich mixture—Fuel-air mixture with a high proportion of fuel.

Rim—That part of a vehicle wheel on which the tire is mounted.

Ring gear—A gear in the form of a ring such as the ring gear on a flywheel or differential.

Rock position—The piston and connecting rod position (top or bottom dead center) at which the crank can rock or rotate a few degrees without appreciable movement of the piston.

Rod—*See* Connecting rod.

Rod cap—The lower detachable part of the connecting rod which can be taken off by removing bolts or nuts so the rod can be detached from the crankshaft.

Roller bearing—A type of bearing with rollers positioned between two races.

Rotor—A part that revolves in a stationary part; especially the rotating member of an electrical mechanism.

SAE—Society of Automotive Engineers.

SAE horsepower—A measurement based upon number of cylinders and cylinder diameter.

Scooter—A small version of a motorcycle.

Sealed-beam—A special type of headlight in which the reflector and lens are sealed together to enclose and protect the filaments.

Self-induction—A property of a circuit which causes it to magnetically affect voltage and current in the circuit.

Semitrailer—A type of trailer supported at the rear by attached wheels and at the front by the truck-tractor; the truck-tractor can be coupled and uncoupled by means of fifth wheel.

Separator—In the storage battery, the wood, rubber, or glass mat strip used as insulator to hold the battery plates apart.

Series circuit—The electrical circuit formed when two or more electrical devices have unlike terminals connected together (positive to negative) so that the same current must flow through all.

Shackle—A swinging support that permits a leaf spring to vary in length as it is deflected.

Shim—A strip of copper or similar material, used under a bearing cap for example, to adjust bearing clearance.

Shimmy—Abnormal sidewise vibration, particularly of the front wheels.

Shock absorber—A device placed at a vehicle wheel to regulate spring rebound and compression.

Short circuit—In electrical circuits, an abnormal connection that permits current to take a short path or circuit, thus by-passing important parts of the normal circuit.

Shroud—Forward subassembly of a body or cab containing dash, cowl, and instrument panel. Also, a hood placed around a fan to improve fan action.

Shunt—Parallel connections, in a portion of an electrical circuit.

Side car—A car attached to a motorcycle for carrying a passenger or cargo.

Slip joint—In the power train, a variable-length connection that permits the propeller shaft to change effective length.

Solenoid—A coil of wire that exhibits magnetic properties when electric current passes through it.

South pole—The pole of the magnet into which it is assumed the magnetic lines of force pass.

Spark plug—The assembly that includes a pair of electrodes which has the purpose of providing a spark gap in the engine cylinder.

Specific gravity—The ratio of the weight of a substance to weight of an equal volume of chemically pure water at 39.2° F.

Speed—Rate of motion.

Speedometer—An indicating device, usually connected to the transmission, that indicates the speed of motion of the vehicle.

Spider—In planetary gear sets, the frame, or part, on which the planetary gears are mounted.

Spiral bevel gear—A bevel gear having curved teeth.

Spline—Slot or groove cut in a shaft or bore; a splined shaft onto which a hub, wheel, etc., with matching splines in its bore is assembled so the two must engage and turn together.

Sprag unit—A form of overrunning clutch; power can be transmitted through it in one direction but not in the other.

Springs—Flexible or elastic members that support the weight of a vehicle.

Spur gear—A gear with radial teeth parallel to the axis.

Starter—In the electrical system, the motor that cranks the engine to get it started.

Starting system—The electrical system, including the starter battery, cables, switch and controls, that has the job of starting the engine.

Static electricity—Accumulated electrical charges, usually considered to be those produced by friction.

Steering gear—That part of the steering system, located at the lower end of the steering shaft, which carries the rotary motion of the steering wheel to the vehicle wheels for steering.

Steering geometry—Difference in angles between the two front wheels and the car frame during turns; the inside wheel turns more sharply than the other wheel turns since it must travel on an arc of a smaller radius. Also called *toe-out during turns.*

Steering linkage—Linkage between steering gear and vehicle wheels.

Steering system—The system of gears and linkage in the vehicle that permits the driver to turn the wheels for changing the direction of vehicle movement.

Storage battery—A lead-acid electrochemical device that changes chemical energy into electric energy. The action is reversible; electric energy supplied to the battery stores chemical energy.

Stroke—The movement, or the distance of the movement, in either direction, of the piston travel in an engine.

Sulfation—A crystalline formation of lead sulfate on storage battery plates.

Sun gear—In a planetary gear system, the central gear.

Supercharger—A device used in connection with engine fuel-air systems to supply more air at greater pressure to the engine, thereby increasing volumetric efficiency.

Suppression—In the electrical system, the elimination of stray electromagnetic waves due to action of ignition, generator, etc., so that they cannot be detected by radio.

Suspension—The system of springs, etc., supporting the upper part of a vehicle on its axles or wheels.

Swaybar—A connecting bar placed between wheel supports, parallel to the axles, which prevents excessive vehicle roll or sway on turns.

Switch—In the electrical system, a device used to open or complete an electrical circuit.

Synchromesh—A name designating a certain type of transmission which has the virtue of permitting gear-ratio shifts without gear clashing.

Synchronize—To make two or more events or operations occur at the same time.

Tachometer—A device for measuring revolutions per minute.

Tactical vehicle—Vehicle designated primarily to meet field requirements in direct connection with combat, tactical operations, and the training of troops for combat.

Tandem axles—Two axles one placed directly in front of the other.

Taper—To make gradually smaller toward one end; a gradual reduction in size in a given direction.

TDC—Top dead center; the position of the piston when it reaches the upper limit of travel in the cylinder.

Temperature gage—An indicating device in the cooling system that indicates the temperature of the coolant and gives warning if excessive engine temperatures develop.

Tension—A stress caused by a pulling force.

Thermal efficiency—Ratio between the power output and the energy in the fuel burned to produce the output.

Thermostat—A device for automatic regulation of temperature.

Third-brush generator—An auxiliary brush which regulates the current output of the generator by increasing or decreasing the field coil current.

Three-quarter trailer—Trailers, usually 2-wheeled; used for light loads. The load is practically balanced on the trailer suspension, although some of the load is thrust on the truck-tractor connection.

Throttle—A mechanism in the fuel system that permits the driver to vary the amount of fuel-air mixture entering the engine and thus control the engine speed.

Throttle valve plate—The disk in the lower part of the carburetor air horn that can be tilted to pass more or less fuel-air mixture to the engine.

Thrust—A force tending to push a body out of alinement. A force exerted endwise through a member upon another member.

Tie rod—A rod connection in the steering system between wheels.

Timing—Refers to ignition or valve timing and pertains to the relation between the actions of the ignition or valve mechanism and piston position in the cylinder.

Tire—The rubber and fabric part that is assembled on the wheel rim and filled with compressed air (pneumatic type).

Toe-in—The amount in inches that the front of the front wheels point inward.

Torqmatic transmission—A special type of transmission which includes a torque converter; it is designed for heavy-vehicle application.

Torque—A twisting or turning effort. Torque is the product, of force times the distance, from the center of rotation at which it is exerted.

Torque converter—A special form of fluid coupling in which torque may be increased (at expense of speed).

Torque rod—Arm or rod used to insure accurate alinement of an axle with the frame and to relieve springs of driving and braking stresses.

Torque-tube drive—The type of rear-end arrangement which includes a hollow tube that encloses the propeller shaft and also takes up stresses produced by braking and driving.

Torque wrench—A special wrench with a dial that indicates the amount of torque in pound-feet being applied to a bolt or nut.

Torsional vibration—Vibration in a rotary direction; a portion of a rotating shaft that repeatedly moves ahead, or lags behind, the remainder of the shaft is exhibiting torsional vibration.

Torus—Rotating member of fluid coupling.

Track—The endless tread on which a tank rides.

Tracklaying vehicle—A vehicle that uses tracks instead of wheels for mobility.

Traction—The force exerted in drawing a body along a plane as when a truck-tractor pulls a semitrailer.

Tractive effort—The pushing effort the driving wheels can make against the ground, which is the same as the forward thrust or push of the axles against the vehicle.

Tractor—A motor vehicle (wheeled or tracked) especially designed to tow trailers.

Trailer—A vehicle without motive power towed by a motor vehicle, designed primarily for cargo carrying.

Transfer—The auxiliary assembly for applying power to both forward and rear propeller shafts, and to front wheels as well as rear wheels.

Transmission—The device in the power train that provides different gear ratios between the engine and driving wheels, as well as reverse.

Transmission brake—A brake placed at the rear of the transmission, usually used for parking.

Tread—The design on the road-contacting surface of a tire which provides improved frictional contact.

Truck-tractor—A motor vehicle especially designed to tow semitrailers.

Trunnion—Either of two opposite pivots or cylindrical projections from the sides of a part assembly, supported by bearings, to provide a means of swiveling or turning the part or assembly.

Trunnion axle—A supporting axle which carries a load with other axles attached to it. Its use as a part of a bogie permits independent wheel action in a vertical plane and within designed limits.

Turbine—A mechanism containing a rotor with curved blades; the rotor is driven by the impact of a liquid or gas against the curved blades.

Turret traversing mechanism—A mechanism for rotating a tank turret on a horizontal plane.

Two-stroke-cycle engine—An internal combustion engine requiring but two piston strokes to complete the cycle of events that produce power.

Universal joint—A device that transmits power through an angle.

Unsprung weight—Weight of a vehicle that is not supported by springs.

Vacuum—A space entirely devoid of matter.

Vacuum advance—The mechanism on an ignition distributor that advances the spark in accordance with vacuum in the intake manifold.

Vacuum brakes—Vehicle brakes that are actuated by vacuum under the control of the driver.

Vacuum pump—A pump, used in a vaccum brake system (for example), that produces a vacuum in a designated chamber.

Vacuum switch—In the starting system, an electric switch that is actuated by vacuum to open the starting system control circuit as the engine starts, producing a vacuum in the intake manifold.

Valve—A mechanism that can be opened or closed to allow or stop the flow of a liquid, gas, or vapor from one to another place.

Valve seat—The surface, normally curved, against which the valve operating face comes to rest, to provide a seal against leakage of liquid, gas, or vapor.

Valve seat insert—Metal ring inserted into valve seat; made of special metal that can withstand operating temperature satisfactorily.

Valve spring—The compression-type spring that closes the valve when the valve-operating cam assumes a closed-valve position.

Valve tappet—The part that rides on the valve-operating cam and transmits motion from the cam to the valve stem or push rod.

Valve timing—Refers to the timing of valve closing and opening in relation to piston position in the cylinder.

Valve train—The train of moving parts to the valve that causes valve movement.

Vapor lock—A condition in the fuel system in which gasoline has vaporized, as in the fuel line, so that fuel delivery to the carburetor is blocked or retarded.

Velocity—The rate of motion or speed at any instant, usually measured in miles-per-hour or feet-per-second or minute.

Venturi—In the carburetor, the restriction in the air horn that produces the vacuum responsible for the movement of fuel into the passing air stream.

Vibration—An unceasing back and forth movement over the same path; often with reference to the rapid succession of motions of parts of an elastic body.

Volatility—A measurement of the ease with which a liquid turns to vapor.

Volt—Unit of potential, potential difference, or electrical pressure.

Voltage regulator—A device used in connection with generator to keep the voltage constant and to prevent it from exceeding a predetermined maximum. (One of the three units comprising a generator regulator.)

Volumetric efficiency—Ratio between the amount of fuel-air mixture that actually enters an engine cylinder and the amount that could enter under ideal conditions.

Volute springs—Helical coil springs made from flat steel tapered both in width and thickness.

V-type engine—Engine with two banks of cylinders set at an angle to each other in the shape of a "V."

Wander—To ramble or move without control from a fixed course, as the front wheels of a vehicle.

Water jacket—A jacket that surrounds cylinders and cylinder head, through which coolant flows.

Water manifold—A manifold used to distribute coolant to several points in the cylinder block or cylinder head.

Water pump—In the cooling system, the pump that circulates coolant between the engine water jackets and the radiator.

Wheel alinement—The mechanics of keeping all the parts of the steering system in correct relation with each other.

Wheel brake—A brake that operates at the wheel, usually on a brake drum attached to the wheel.

Wheel cylinder—In hydraulic braking systems, the hydraulic cylinder that operates the brake shoes when hydraulic pressure is applied in the cylinder.

Winch—A mechanism actuating a drum upon which a cable is cooled, so that when a rotating power is applied to the drum, a powerful pull is produced.

Wobble plate—That part of a special type of pump (wobble pump) which drives plungers back and forth as it rotates to produce pumping action. It is a disk, or plate, set at an angle on a rotating shaft.

Work—The result of a force acting against opposition to produce motion. It is measured in terms of the product of the force and the distance it acts.

Worm gear—A gear having concave, helical teeth that mesh with the threads of a worm. Also called a *worm wheel.*

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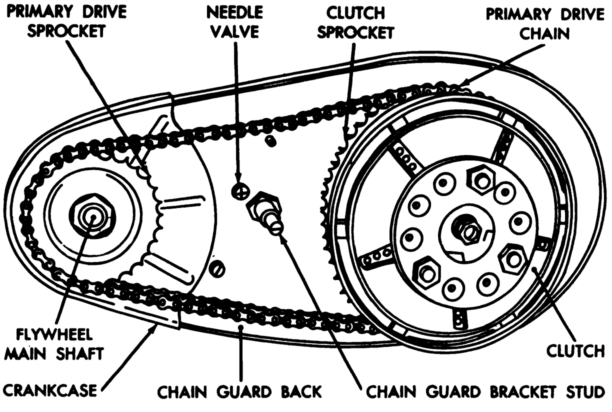
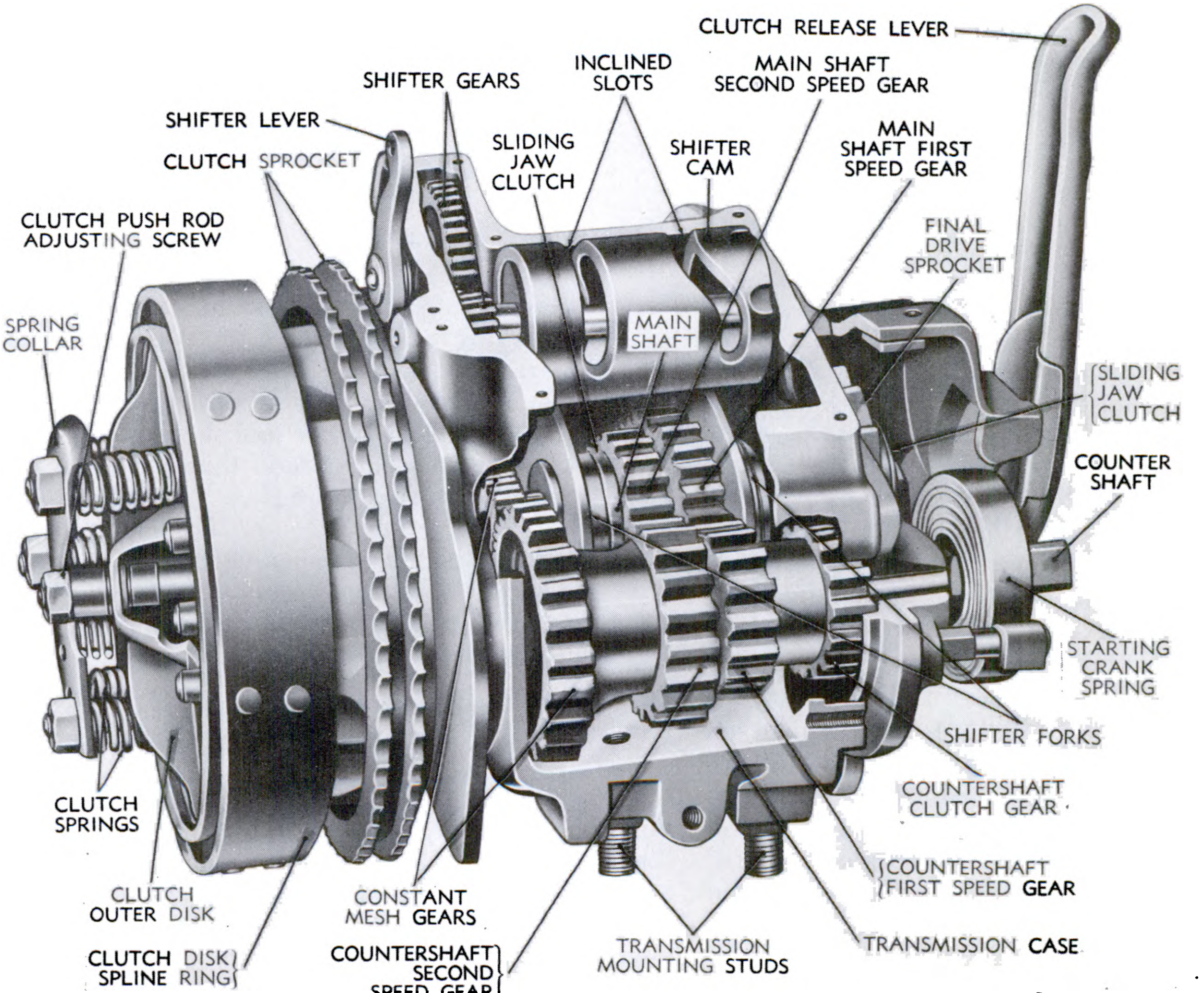

PRIMARY DRIVE SPROCKET
NEEDLE VALVE
CLUTCH SPROCKET
PRIMARY DRIVE CHAIN
FLYWHEEL MAIN SHAFT
CRANKCASE
CHAIN GUARD BACK
CHAIN GUARD BRACKET STUD
CLUTCH

RA PD 184169

Figure 640. Dry-type primary drive.

as the driving disks. The others are pinned or keyed to the transmission main shaft (fig. 642) and act as the driven disks. The disks can be of either dry or wet type, depending on the type of primary drive used.

b. Coil springs are used to force the driving and driven disks together when the clutch is engaged. In the disengaged position the coil springs are compressed and do not exert any pressure against the disks. The clutch is engaged and disengaged by means of a foot-operated clutch pedal, operating through suitable linkage. A flexible cable and a clutch release lever that bears against a push rod which, in turn, compresses the


CLUTCH RELEASE LEVER
SHIFTER GEARS
INCLINED SLOTS
MAIN SHAFT SECOND SPEED GEAR
SHIFTER LEVER
CLUTCH SPROCKET
SLIDING JAW CLUTCH
SHIFTER CAM
MAIN SHAFT FIRST SPEED GEAR
CLUTCH PUSH ROD ADJUSTING SCREW
FINAL DRIVE SPROCKET
MAIN SHAFT
SPRING COLLAR
SLIDING JAW CLUTCH
COUNTER SHAFT
STARTING CRANK SPRING
SHIFTER FORKS
COUNTERSHAFT CLUTCH GEAR
CLUTCH SPRINGS
COUNTERSHAFT FIRST SPEED GEAR
CLUTCH OUTER DISK
CONSTANT MESH GEARS
TRANSMISSION CASE
CLUTCH DISK SPLINE RING
COUNTERSHAFT SECOND SPEED GEAR
TRANSMISSION MOUNTING STUDS

RA PD 186799

Figure 641. Three-speed progressive transmission.

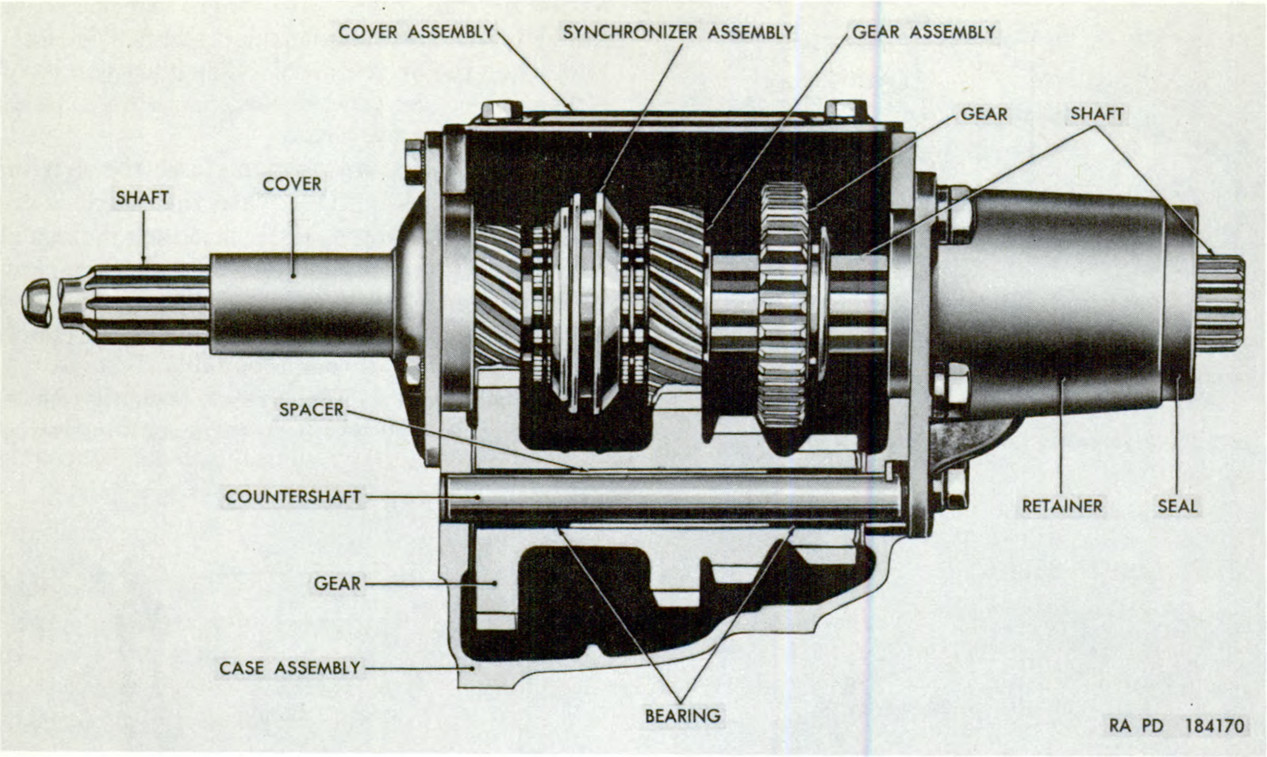


Figure 642. Three-speed selective transmission.

coil springs, are used in one model; a release rod and a clutch release lever that rotates a release worm are used in another. The clutch is engaged and released by setting the clutch release pedal toe and heel pads in either the up or down positions.

369. Transmission

a. General. Motorcycle transmissions provide three forward speed ratios for selection of desired gear reductions between the engine and rear wheel. Progressive or selective type transmissions are used. In the progressive type, when shifting from low to high or from high to low, it is necessary to pass through the intermediate speed. In the selective type, the shift can be made from any speed to the neutral position.

b. Progressive Transmission. The progressive transmission used on motorcycles is of the constant-mesh type with three speeds forward (fig. 641). The main shaft gears and mating countershaft gears float on their shafts, and are in constant mesh. Power is transmitted through the gears by sliding jaw clutches which engage with slots or splines in the gear hubs. The shifter forks that move the sliding clutches are actuated by the rotation of a shifter cam. As the shifter cam is rotated by the gear shift linkage, shifter fork pins follow the inclined slots cut in the cam and move the shifter forks back and forth, into and out of mesh with the gears.

c. Selective Transmission. The selective transmission (fig. 642) used on motorcycles is similar in principle to those used on other automotive vehicles (par. 200) except that no reverse speed is provided.

370. Final Drive

The motorcycle final drive consists of the final-drive sprocket (fig. 641) mounted on the outer extension of the output end of the transmission main shaft, the rear wheel sprocket, and the final-drive chain. The final-drive chain is constructed with rollers on single-row connecting links. The chain is either hand-lubricated or, as in some models, lubricated by a chain oiler, which is an adjustable needle valve connected to the engine lubrication system.

CHAPTER 27

SCOOTERS

371. Types

The two-wheel motor scooter designed primarily for airborne operations (fig. 643), the scooter with sidecar (fig. 644), and the three-wheel, package delivery motor scooter (fig. 645) are three variations of the scooter. They are all similar in construction and operation.

372. Construction

a. Scooters are powered by single-cylinder gasoline engines and are driven by a power train that is similar to that used on motorcycles. The sheet-steel main frame assembly, combined with a U-shaped, channel-steel, rear wheel frame, serves as the foundation for mounting the scooter components. The front end of the main frame has a spindle housing tube with bushing-type bearings for mounting the front fork. Handlebars for steering are part of the front fork.

b. The engine, clutch, and transmission are mounted in the cradle, directly in front of the rear wheel, with the fuel tank and saddle mounted directly above.

373. Engine

a. The scooter engine is an air-cooled, single-cylinder, 4-stroke cycle, gasoline engine of approximately 4 hp. Fins are provided on the cylinder and cylinder head for improved cooling.

b. A single-throw crankshaft, supported by tapered roller bearings, with conventional piston and connecting rod, is used. The camshaft for the intake and exhaust valves is driven by the

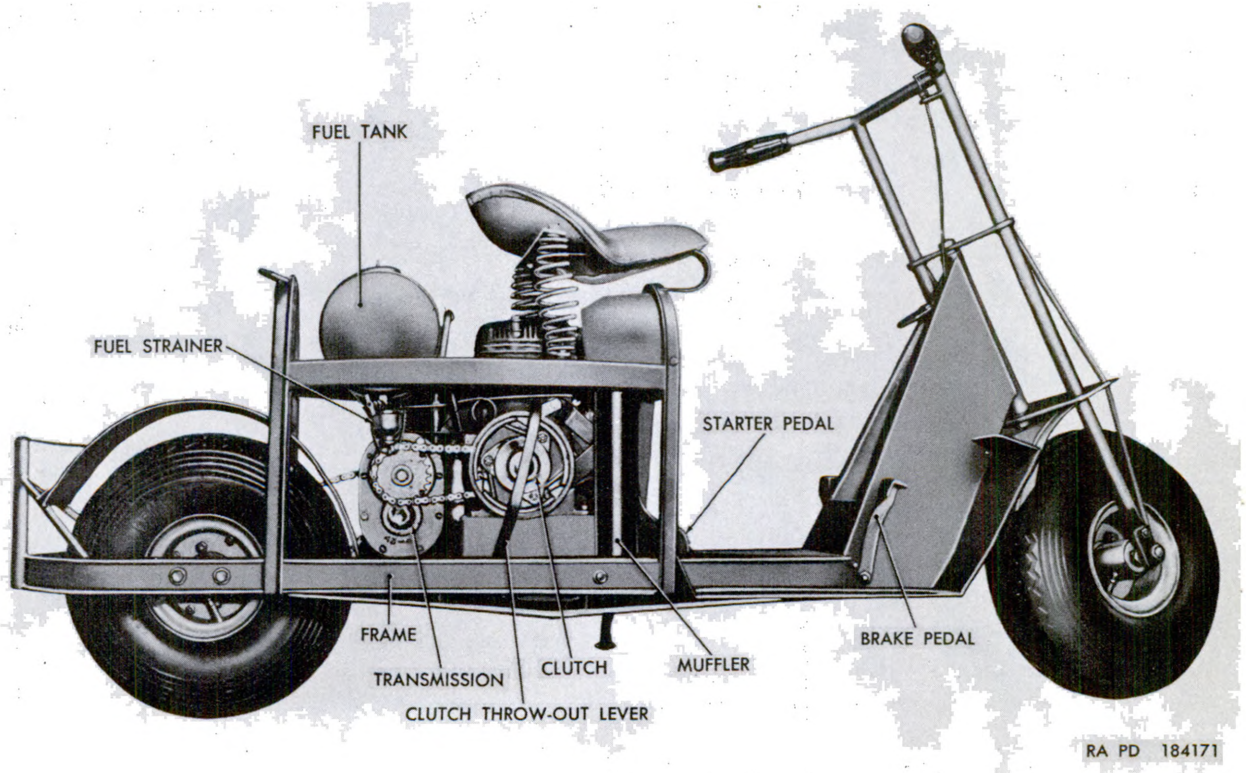


Figure 643. Two-wheel motor scooter for airborne operations.

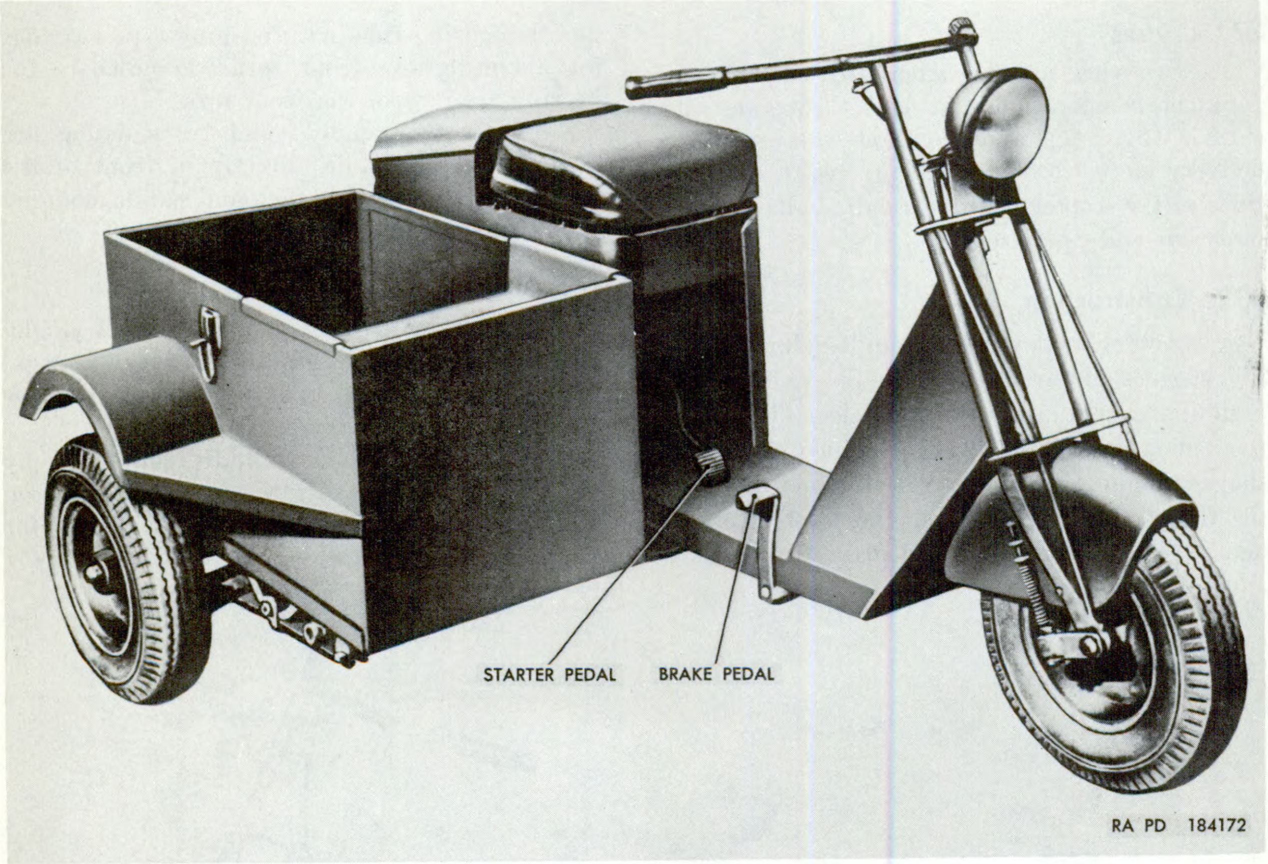

STARTER PEDAL
BRAKE PEDAL
RA PD 184172

Figure 644. Motor scooter with sidecar.

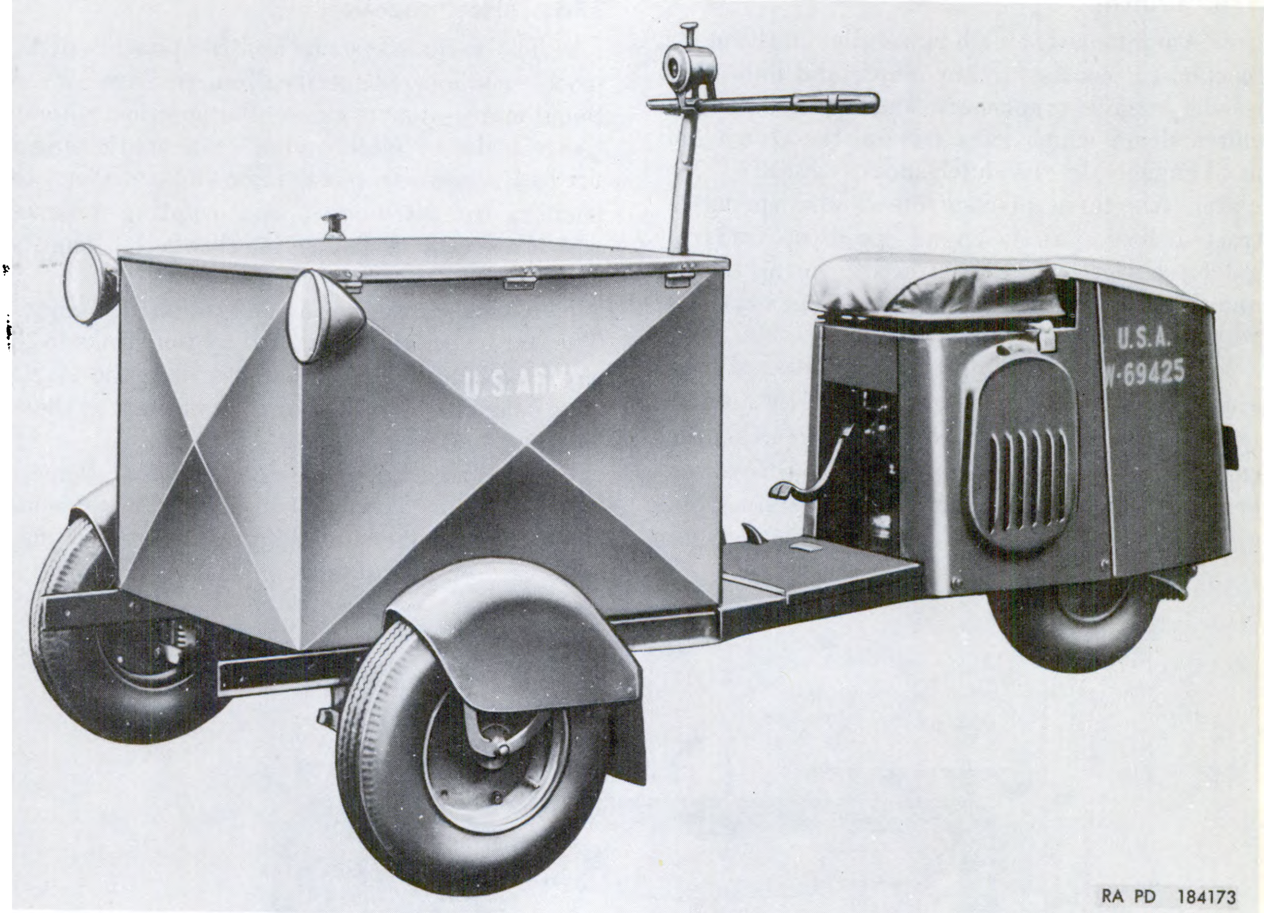

U.S. ARMY
U.S.A.
W-69425
RA PD 184173

Figure 645. Three-wheel package delivery motor scooter.

crankshaft through timing gears. A starter gear is mounted on one end of the camshaft.

c. The engine is completely lubricated by splash from an oil trough (fig. 646) in the subbase. The trough is fed by a plunger-type oil pump, which is driven directly from a cam on the camshaft through an oil plunger (fig. 647) extension mounted on the inner sidewall of the engine base.

374. Clutch

a. An automatic clutch is installed in the motor scooter. It consists of the clutch and hub keyed to the engine crankshaft and a friction-lined clutch drum which runs free on the clutch hub until engaged by the clutch shoes (fig. 648). The clutch has three pivot-mounted and spring-retracted shoes. As the engine speeds up, centrifugal force overcomes the retracting spring tension and throws the shoes outward to engage the drum, which carries the primary chain sprocket.

b. The clutch is equipped with a manually operated declutching device, controlled by a clutch pedal and linkage. Depressing the clutch pedal causes pressure to be applied to the throw-out bearing, which actuates the bearing retainer pins and throw-out links, releasing the clutch shoes from the drum.

375. Fuel System

a. The scooter fuel system consists of a fuel tank, strainer with sediment bowl, shutoff valve, and gravity-fed carburetor. An oil-bath type air cleaner is used.

b. The carburetor is of the side outlet, plain tube type with a fixed venturi, such as is used on motorcycles.

376. Miscellaneous

a. The various systems and components of the scooter not covered specifically herein are conventional and similar to those used on other automotive vehicles or motorcycles. The spark plug is fired by a magneto consisting of an armature, capacitor, contact points, and rotating magnets which are cast in the engine flywheel. The flywheel acts as the magneto rotor.

b. A kick starter is provided to start the engine. The starter pedal is connected by four links to the starter quadrant, which meshes with the starter gear mounted on the end of the camshaft as shown in figure 649.

c. The transmission is a conventional, 2-speed, forward unit. The brake on the rear wheel is mechanical, internal-expanding, cam-operated, such as is used on motorcycles.

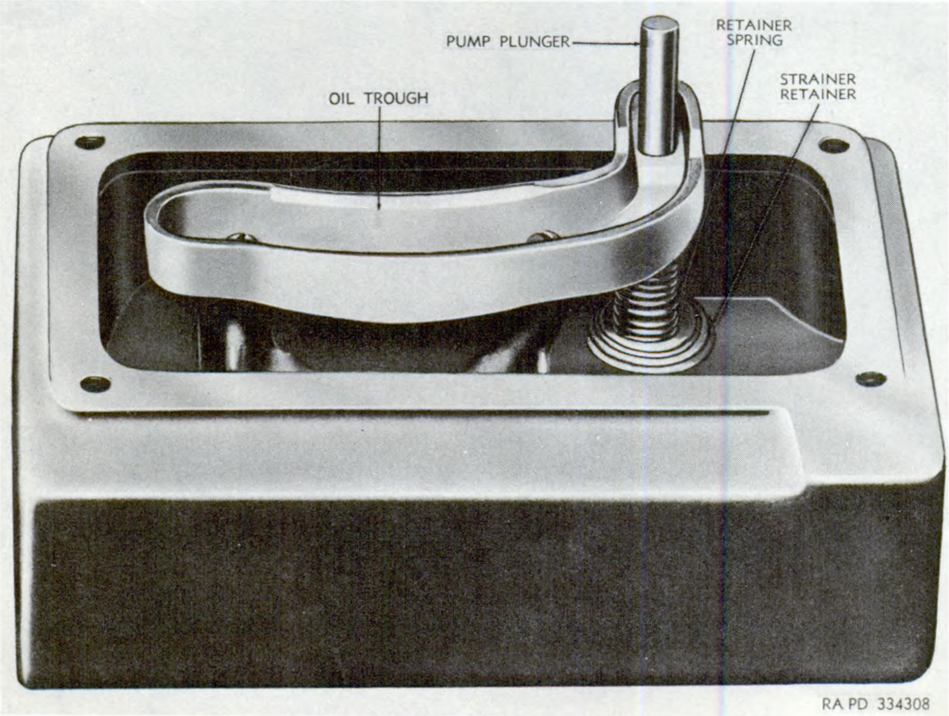


Figure 646. Oil pump trough.

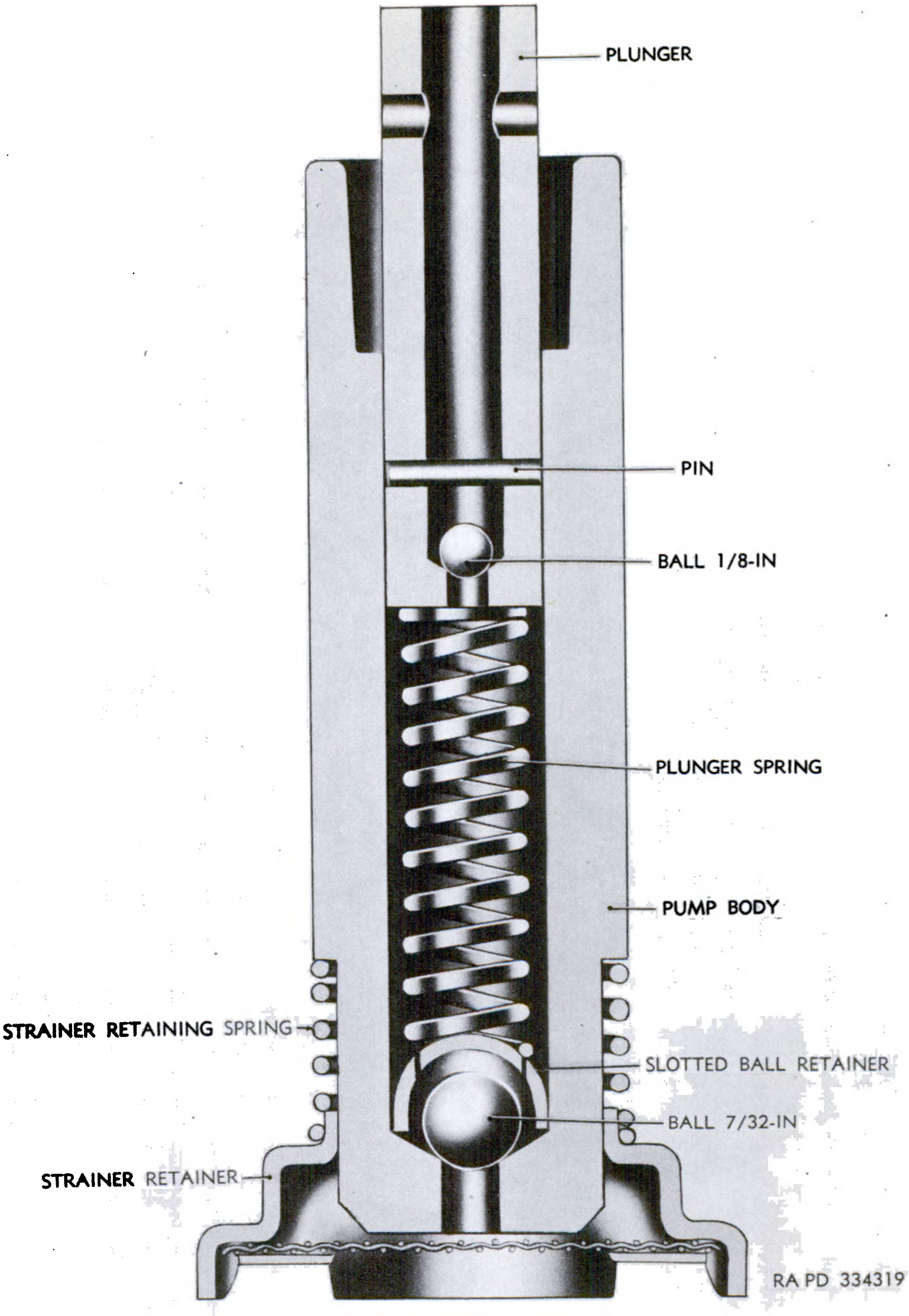

PLUNGER
PIN
BALL 1/8-IN
PLUNGER SPRING
PUMP BODY
STRAINER RETAINING SPRING
SLOTTED BALL RETAINER
BALL 7/32-IN
STRAINER RETAINER
RA PD 334319

Figure 647. Oil pump plunger—cross sectional view.

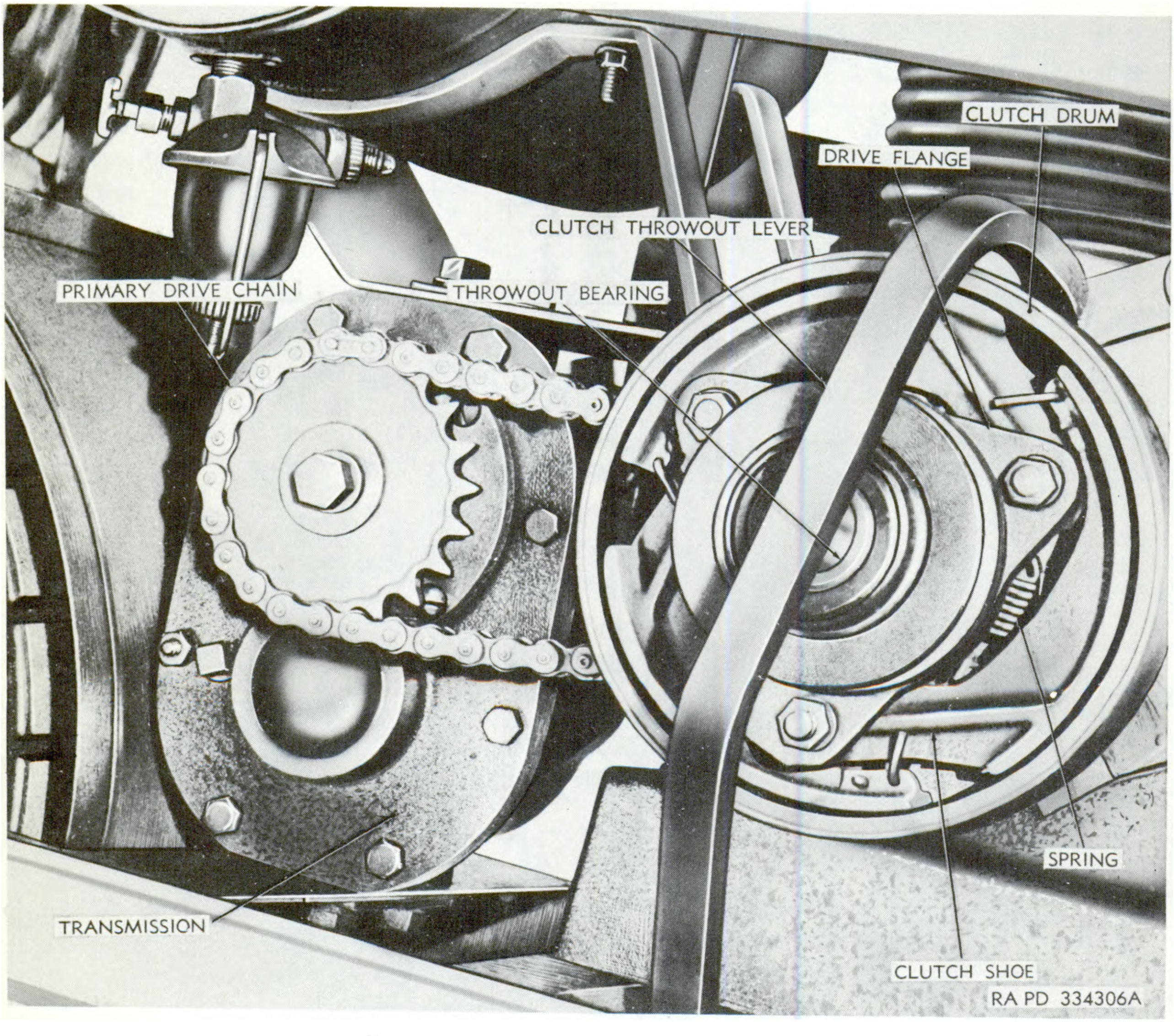

CLUTCH DRUM
DRIVE FLANGE
CLUTCH THROWOUT LEVER
PRIMARY DRIVE CHAIN
THROWOUT BEARING
SPRING
TRANSMISSION
CLUTCH SHOE
RA PD 334306A

Figure 648. Scooter clutch and transmission.

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